THE LUNAR ORBITER PHOTOGRAPHIC SYSTEM

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ABSTRACT

With the highly successful flights of Lunar Orbiters I, II, and III in August and November of 1966, and February 1967, and with further Orbiter launches scheduled during 1967, the NASA is well along toward accomplishment of the Lunar Orbiter Program objectives. These objectives include the primary goal of photography of the Lunar surface to aid in the selection of safe landing sites for Project Apollo, as well as secondary goals of obtaining information of general scientific interest on the origin and history of the Moon and its gravitational parameters.

The Lunar Orbiter System is described, with emphasis on the design and in-flight performance of the Photographic System. Consideration is given to both the problems and advantages of film-type photographic systems for deep space applications. Selected photographic and performance data from Lunar Orbiter Missions I, II, and III are presented.

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INTRODUCTION

With the announcement in April of this year of the selection of the landing sites for the first Apollo mission to the Moon, the United States and the National Aeronautics and Space Administration were announcing the success of the first phase of one of the unmanned programs that made this landing site selection possible; the Lunar Orbiter. Lunar Orbiter is one of three NASA programs whose goal is to provide sufficient information on the characteristics and environment of the Moon to make possible intelligent and safe decisions on landing sites for Apollo astronauts before the end of this decade (fig. 1). Ranger, the first of the three, completed its program in early 1965 utilizing a television system to return thousands of photographs of three interesting regions on the lunar surface. Surveyor has scored two successes in conducting a soft-landing program to investigate specific areas of interest to the manned program, and has also returned thousands of television photographs, some with detail down to the millimeter level. However, while Surveyor provides vital data on soil bearing strength and high-resolution detail of the surface, the job of wider area searching and certification fell to a more versatile spacecraft, one capable of covering thousands of square kilometers of the lunar surface on a single mission at a resolution near 1 meter - the Lunar Orbiter.

The design phase of the Lunar Orbiter program was begun in late 1963. The NASA Langley Research Center was assigned management of the program, with The Boeing Company as prime spacecraft contractor and Eastman Kodak Company responsible for the photographic system. Initial plans called for the first launch to occur in June of 1966; the first launch actually occurred on August 10, 1966, and after successful injection onto translunar trajectory, the spacecraft became Lunar Orbiter I. This vehicle was followed on November 6, 1966, by Lunar Orbiter II and on February 4, 1967, by Lunar Orbiter III.

Lunar Orbiter I returned excellent wide-angle† photographs of nine sites in the Apollo zone of interest (fig. 2). Problems with relative timing between the image motion compensation and tripping of the focal plane shutter degraded the 610-mm lens photography. Lunar Orbiter II returned excellent high-resolution (610-mm) photographs of 13 primary sites in the Apollo zone. The

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†The term "wide-angle" is used here in reluctant surrender to the forces of the Public Information Office. The lens involved has a focal length of 80 mm and will be described in detail later.

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Ranger 8 impact point was located in one of these photographs. In addition to farside photographs, a number of spectacular oblique photographs of prominent lunar features were obtained. Lunar Orbiter III also scored a success, photographing 13 primary Apollo zone sites, adding to the farside coverage and zooming in on more oblique shots for scientific purposes.

It was possible, after analysis of the results of Orbiters I, II, and III, to select the landing sites for targeting the first Apollo mission, and to designate the fourth and fifth Orbiters, earlier planned to help complete the Apollo requirements, to conduct broader missions of more general scientific interest. Thus Lunar Orbiter D, scheduled for a May 1967 launch, is assigned the task of photographing almost the entire Moon at resolutions varying from about 70 meters on the nearside to roughly equivalent to Earth-based telescopic resolution on the farside. Lunar Orbiter E, fifth of the series, is tentatively scheduled to take a closer look at some of the features identified in Lunar Orbiter D photography, as well as to conduct further Apollo work if required. While Lunar Orbiters I, II, and III operated from orbits with inclinations up to 21° (fig. 3), both the fourth and fifth Lunar Orbiters will work from an orbit of 85° inclination, thus making possible coverage of virtually the entire surface of the Moon.

THE SPACECRAFT

The Lunar Orbiter spacecraft (fig. 4) is a three-axis stabilized vehicle weighing about 850 pounds at launch. Electrical power is provided by four solar panels, with batteries providing for limited electrical loads during periods of sunset. Two antennae, one high-gain directional and one omnidirectional, provide the means of communication with the spacecraft. Thermal control for the vehicle is primarily passive, with a limited number of heaters being employed where required. The attitude reference for yaw and pitch is provided by a sun sensor in the equipment mounting plate so that the solar panels normally face the sun. The roll axis reference is provided by an electro-optical sensor which tracks the star Canopus, second brightest in the heavens. This attitude results in the high-gain antenna being pointed toward Earth, with an assist from a rotatable boom on the unit. The spacecraft departs from the Sun-Canopus orientation only to point the liquid rocket engine for velocity changes or to point its cameras for photography. The photographic system is a self-contained dual-camera system, enclosed in a pressurized container which provides the means for maintaining the environmental conditions required for operation of a photographic laboratory in a space environment.

Most functions aboard the spacecraft are controlled by the onboard programer. This unit receives commands from Earth stations and either executes them immediately or stores them for execution at a precise later time. Sufficient memory slots are available to automatically control the spacecraft functions for periods of several hours.

Two auxiliary systems aboard the spacecraft provide information useful both for mission control and for scientific purposes. A group of micrometeoroid detectors is located in a ring just below the fuel tanks. These devices are pressurized cans of known thickness that, when punctured, lose pressure and send a signal of this event to Earth. Two proton-radiation detectors are carried for mission control purposes. Shielding on these detectors approximates that at two critical locations within the photographic system, and telemetered dose values and rates make possible an evaluation of the gravity of any solar proton activity encountered.

MISSION DESCRIPTION

Following launch from Cape Kennedy aboard the Atlas-Agena vehicle (fig. 5), separation from the Agena, and deployment of the solar panels and antennae, the spacecraft begins its 90-hour trip to the Moon. Provision is made for correction of the trajectory en route, using the rocket engine, if necessary. Upon arrival at the vicinity of the Moon, the rocket engine is once again burned to decrease the spacecraft's velocity relative to the Moon and cause it to "fall" into Lunar Orbit.

By carefully selecting the period of the month during which launch takes place, and by controlling the deboost maneuver, the spacecraft is directed into an orbit whose perilune (point of closest approach) occurs over a point on the lunar surface where the morning Sun's rays are making an angle of 15° to 40° with the local horizontal. This is considered favorable lighting, as we shall see later. Since lunar orbit once established maintains an essentially fixed orientation in inertial space, it is necessary only to wait in orbit until rotation of the Moon on its axis brings the targets of interest under the perilune. Refining adjustments to the orbit may be made during this period.

As targets become favorably located under the orbit (fig. 6), the spacecraft is reoriented to look downward and a series of 1, 4, 8, or 16 photographs are exposed. If more coverage is required than a single pass can provide, blocks of coverage can be built up by overlapping photography on successive orbits. Frame to frame forward overlap may be either 5 percent and 88 percent on 610-mm and 80-mm photographs, respectively, or 52 percent on 80-mm photographs with gaps between 610-mm frames. In either case, the 80-mm lens system provides stereoscopic coverage. On a complex mission, such as Lunar Orbiter III performed, photographs may be taken every orbit, most of them within the area bounded by 5° north and south latitude and 45° east and west longitude, the Apollo area of interest. However, some slack periods do exist, and the availability of this time, together with requirements for frequent movement of film, have resulted in photographs of great scientific and general interest (figs. 16 and 17 and 19 through 21).

Following conclusion of photography and read-back of all photographs, the Lunar Orbiter is put into a cruise condition and is interrogated from time to time for information on its scientific experiments and its reaction to gravitational perturbations of the Moon. It is also used as a tracking target by the Apollo Manned Space Flight Network, whose job it will be to track the Apollo Moonship and provide communications with the astronauts.

THE PHOTOGRAPHIC SYSTEM

In figure 7 we see that the photographic system is housed in a thin aluminum shell, only the lower half of which is shown. The lenses peer through quartz windows in the upper half of the shell. After launch, pressure within the shell is maintained between 1- and 2-psia nitrogen, with a high-pressure resupply of nitrogen available in the event of small leaks. Temperature control within the unit is by exchange with the spacecraft equipment mounting plate through painted fins located on the underside of the shell. Temperatures are increased, when necessary, by automatically controlled heaters of the electrical resistance type. Control of temperatures within $\pm 1^{\circ}$ is typical within the camera area of the system. Humidity is controlled at 50 ± 10 percent with potassium thiocyanate pads.

Figure 8 provides a schematic look inside the photographic system, which is seen to be comprised on three basic sections; camera, processor, and readout. Not shown in this diagram are the many interconnections which are necessary to control the functions of the three basic sections. Examining each section in detail, we see, in figure 9, an artist's sketch of the camera. The film used is Eastman Kodak Type SO-243, High Definition Aerial Film, 70 mm in width. As film is pulled from the supply, it passes first through the focal plane of the 80-mm lens (or, some insist, wide-angle lens). This lens-shutter assembly is an off-the-shelf unit, modified from f/2.8 to f/5.6 with a waterhouse stop. Modification also includes elimination of all shutter-speed settings save 1/25, 1/50, and 1/100 second. A 0.21 neutral density filter is added to the lens to help achieve a balance in exposure with the 610-mm lens. Simultaneously with exposure of the 80-mm format, exposure also occurs on the 610-mm lens system, and a 20 bit code showing the time the photograph was taken is exposed adjacent to the 80-mm format. The 610-mm lens, a modification of an earlier design by Pacific Optical, used a folding mirror and a focal plane shutter to expose a format approximately 5° by 20°, versus the 80-mm format of approximately 35° square. Following each exposure, the film is advanced exactly 11.690 inches. This brings the last 80-mm frame to a position just short of the 610-mm platen, brings fresh film onto both platens, and readies the system for the next exposure. In this manner, the 80-mm and 610-mm frames are interlaced on the film.

The frame layout is illustrated in figure 10. In this figure we also see the preexposed edge data and the detail of the saw-tooth edge marks. The edge data are preprinted onto the SO-243 film before it is loaded into the photographic system and is processed at the same time as the accompanying lunar data. Various patterns are used, including resolving power targets, reference numbers, and a 9-step gray scale, useful for sensitometric control in ground data reduction. The edge-mark pattern provides a frame coordinate system for data reduction, and appears in the final photograph illuminated by the natural light of the exposure. Also present on the film is a pattern of preexposed Reseau crosses. A more detailed discussion of this Reseau pattern will be given later.

Approach to the lunar surface closer than about 200 kilometers makes image motion a significant degrading factor in photography, so image motion compensation is provided for both lens systems. To accomplish this, a portion of the 610-mm field of view corresponding to the "bump" on the folding mirror is fed to the velocity/height sensor, located physically above the camera plane. This optical signal is analyzed by the sensor, time-correlated, interpreted, and translated into a servomechanism output which is used to drive both camera platens so as to null out image motion. An electrical output from the sensor shaft also provides information used by the camera programer to set precise framing rates to control forward overlap between photographs.

Since the camera may take up to 20 photographs in rapid succession at framing rates as high as 1.6 seconds per photograph, buffer storage is provided for the film between the camera and processor. In figure 11, film is seen pulled from the camera by the film advance motor and made available to a spring-loaded device known as the camera storage looper. This looper can store up to 21 frames of film.

After completion of the photographic pass, the processor is enabled (fig. 12). After being twisted 90° into the processor, the film is laminated with Eastman Kodak Type SO-111 Bimat Film, pre-soaked with Imbibant Type PK 411. Processing of the film to a negative takes place during travel around the processing drum at a controlled temperature of 85° F. After processing, the film and Bimat are delaminated, the Bimat is discarded into the Bimat take-up chamber, and the film passes over the dryer drum, where it is subjected to a temperature of 95° F and moisture is driven off for absorption by pads around the periphery of the drum. Following drying, the film is twisted once again through 90°, passing out of the processor and into the readout looper (fig. 11). At this point the readout looper serves only a control function, becoming partially filled with film, and then signaling the motor on the take-up spool to empty it once again. In this manner the photographs are exposed, processed, dryed, and stored, ready for transmission to Earth.

Two readout modes are possible. In normal operation, only selected readout is conducted prior to completion of all photography and processing. After completion of processing, the Bimat is cut by a hot wire device, making the processor freewheeling, and readout proceeds until all data have been examined. The selected readout mode makes data available at any time, and is limited only by the capacity of the readout looper.

Film travel during readout is opposite to the direction of photography and processing. In the readout assembly (fig. 13), the film advances in 2.5-mm segments. During a 23-second pause between advances, the film is clamped in the readout gate and scanned with a raster of about 287 lines/mm. Light for this scan is generated by the line scan tube, which provides an 800-Hz horizontal sweep of an electron beam across a revolving phosphor drum anode. The resulting flying spot, approximately 200 microns in diameter, is minified 22 times and imaged on the emulsion side of the film. The vertical component of the raster is generated by moving the minifying lens (scanner lens) at a precise rate across the film. After scan of each segment, the film advances, the lens reverses, and the next segment is canned in the opposite direction. Light transmitted by the film is collected by optics and fed to the photomultiplier tube, which in turn feeds a video amplifier that sends a 0- to 5-volt, 0- to 240-Hz video signal to the communications subsystem for transmission to Earth. The film is thus readout in "framelets," each 2.5 mm by 65 mm and each requiring about 23 seconds to transmit. About 43 minutes are required to transmit one "frame," that is, one 80-mm and one 610-mm exposure pair with the associated time code data.

After receipt and processing at one of the Earth stations of the Deep Space Network, the video signal is fed to one of two recording devices. Predetection video recordings are made of each readout sequence, and these constitute the primary data source for future reconstructions and analysis. At the same time, the ground reconstruction electronics are used to regenerate the signal. This device essentially provides the reverse of the spacecraft readout, taking the video signal and driving a kinescope whose line scan is imaged onto moving 35-mm film. Thus each framelet, 2.5 mm by 65 mm in the spacecraft, becomes a framelet 20 mm by 424 mm on the ground (fig. 14). These framelets are then laid side by side to provide reconstruction of all or part of the frames as they existed in the photographic system in lunar orbit.

This, then, is how the system operates. In the following paragraphs we shall examine some of the technical considerations involved in system design, discuss why such a mechanically complex device was chosen to do the job, and examine some of the results from the first film-type deep-space photographic system used by the United States.

LUNAR PHOTOMETRY AND EXPOSURE CONSIDERATIONS

The Moon presents unique problems in exposure determination and in evaluation of the resulting photographs. The absence of an atmosphere, of course, means virtual absence of scatter of light into shadow areas. The lunar surface itself is a backscatterer of light. Numerous formulations have been made in an effort to describe the reflective properties of lunar material, and the photometric function represented by figure 15 is the most widely used device. In the upper diagram, g is the so-called phase angle, or the angle between the observer's line of sight and the incident Sun's rays. The angle α is the projection into the phase plane (Sun-observer plane) of the angle between the observer's line of sight and the normal to the surface at the point under observation.

To understand the use of the photometric function plot, take the simple case of an observer looking vertically downward on a smooth, spherical Moon, that is, α is 0°. If the Sun is at the observer's back, $g = 0^{\circ}$ also, and we have the condition of greatest reflection of light, corresponding to the well-known full Moon. As the angle g increases from 0° toward 90° illumination decreases, until with $g = 90^{\circ}$, the reflected light falls to zero and the observer is looking at the terminator. Note that the angle α is both a measure of surface deviations from a smooth sphere and a measure of the angle between the observer's line of sight and the normal to the surface. For example, the areas drawn in for 20° and 30° operating ranges represent the variation in the reflectance term ϕ over the format of a square field of view of 40° and 60° due only to deviations of the observer's line of sight from the local vertical on a smooth Moon. Since exposure varies directly as ϕ, considerable difference in exposure can occur across a single frame due only to α and g variation. Introduction into this consideration of such lunar features as craters and domes further varies the reflectance as the angle α takes on the additional task of describing deviations from the smooth sphere.

In figures 16 and 17 we see some of the consequences of the Moon's reflective properties. Figure 16 was taken by Lunar Orbiter III of the crater Kepler. The line of sight of the camera was nearly northward. Since the Sun's rays are essentially in the equatorial plane of the Moon, as we look from bottom to top in the photograph we see little change in the average density of the "smooth" areas because the angles g and α change very little. In this case g changes only by a small amount as the phase plane tilts by 20° from bottom to top of the photograph. The uniformity of this photograph is striking. Figure 17 presents an entirely different situation however. This photograph, also taken by Lunar Orbiter III, was taken looking nominally east to west, with the Sun behind the "back" of the camera-observer. Here we see the striking effect of decreasing phase angle (g) as we look from lower left to upper right and the phase angle approaches zero. In the overexposed portion of the frame, even drastic changes in α cannot save us from the near unity value of the reflectance term, and virtually all detail is lost. This view closely approximates the view of an astronaut approaching the area for a landing.

Understanding of the peculiar reflective properties of the lunar surface makes possible slope analysis of the photographs based on assumed values of albedo. Some of these techniques, as well as photogrammetric data reduction techniques applicable to Lunar Orbiter photography, have been treated by Kosofsky[1] and will not be covered here.

Choice of shutter speeds of 1/25, 1/50, and 1/100 second for Lunar Orbiter was originally dictated by the prime mission requirements of 1-meter vertical photography from a 46-km altitude using SO-243 film and f/5.6 lenses. Although it would be less than the truth to state that these exposure times have always provided us with optimum results, the system has performed remarkably well under a wide range of conditions, many of them completely outside the original design concept. The trade of limited exposure adjustment for system simplicity is believed to be justified by the results.

FLIGHT RESULTS AND CONCLUSIONS

It is customary to specify a photographic system's performance in terms of resolving power, that is, a certain minimum number of lines per millimeter resolved in the final image under specified operating conditions. In recent years, the industry has been turning more and more to speaking of photographic performance in terms of modulation transfer, or percentage of object plane information content transferred to the final image plane. In the Lunar Orbiter

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[1]Kosofsky, L. J.: "Topography from Lunar Orbiter Photos," PHOTOGRAMMETRIC ENGINEERING, March 1966, p. 277.

system, both criteria were used. The specification imposed upon the Eastman Kodak Company was in terms of line pairs per millimeter, specifically that the end-to-end system be capable of resolving 76 line pairs per millimeter at 3:1 contrast from a lunar altitude of 46 kilometers. At the same time, the prime contractor accepted a requirement in terms of signal-to-noise ratio; specifically, the system must produce in the final ground film a signal-to-noise ratio of at least 3:1 when photographing a cone 1/2 meter high with a base diameter of 2 meters under typical lunar lighting conditions. For the purpose of determining whether the latter requirements have been satisfied, a great deal of analysis and auxiliary testing has been conducted and some of the results are presented here.

In order to demonstrate signal-to-noise performance, a detailed analysis was undertaken, supplemented by ground testing and examination of the in-flight photographic results. Some of the experimental results are presented in figure 18. This plot compares modulation transfer functions (MTF) for the 610-mm camera system from various sources. The triangular symbols represent the combination of a theoretical MTF for the 610-mm lens, produced by ray tracing techniques, with the measured MTF of Type SO-243 film with Bimat processing. This curve may be designated as the "expected" MTF for the 610-mm camera. The circular symbols represent a measurement of the MTF for the Lunar Orbiter II 610-mm camera. The target in this case was about 4.5:1 contrast. The points marked with squares represent a measurement by the Cornell Aeronautical Laboratories of several 610-mm frames from Lunar Orbiter II.[2] To arrive at these results several steps were followed. First, the total system MTF was measured from the ground film by tracing many shadow edges on crater floors, using edges with relatively low contrast. Next, traces were taken in the edge data on edges of known preflight sharpness to measure the MTF of the scanner system, the communications link, and the ground reconstruction apparatus. This MTF for the scanner, communications, and ground equipment was then divided out to obtain the camera MTF. The Cornell data above 50 to 60 lines/mm must be taken with a grain of salt, as the edges scanned in the edge data ceased to have appreciable frequency content at about this frequency. It is interesting to note that the Cornell values begin to depart from the preflight measured values at about 50 lines/mm. Another factor that must be considered in evaluation of the data is the fact that both the theoretical MTF and the preflight measured MTF do not consider image motion, while the flight measured values do include the effects of image motion. However, even at 40 to 50 lines/millimeter the values which include image motion (C.A.L. measurements) exceed static preflight predictions, indicating that image motion was negligible in the Lunar Orbiter II mission. Computed signal-to-noise ratios for the standard 2-meter base cone, based on measured MTF values, exceed the specification requirements up to phase angles of about 60°. Experimental data on higher phase angles up to the original specification of 50° are not available as a result of operation of the system almost exclusively under the more favorable lighting conditions associated with lower Sun elevations.

A number of preflight calibrations were undertaken to assist in interpretation of the photographs. Measurements of the modulation transfer function and of lens transmittance versus field angle were made on both lenses. Radial

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[2]Working Paper No. 4, Contract No. NAS1-5800, April 25, 1967, unpublished.

and tangential distortion was measured from the beginning on the 80-mm lens, and in preparation for Lunar Orbiter D, distortion measurements have been made on the 610-mm system. To assist in photometric data interpretation, system veiling glare was measured, and studies were undertaken to measure the photometric uniformity of the focal plane shutter. During each mission, a special test film containing tone reproduction blocks, resolution charts, and sine-wave targets is read out from lunar orbit. Finally, the SO-243 film is preprinted not only with the edge data shown in figure 10, but with a pattern of Reseau crosses to aid in recovering the flight film geometry after readout and reassembly. A series of 23 crosses having arm lengths of 100 microns and line weights of about 15 microns is preprinted on the film during the edge printing operation. Repetition of the pattern is such that one 23-mark pattern appears in each framelet. These marks are used primarily for photogrammetric interpretation of the data, but they also serve as useful resolution reference marks, since the line weight of each cross approximates 1 meter from a 46-kilometer lunar altitude.

We have already examined some of the Lunar Orbiter's flight photographs to illustrate certain points within the paper. Numerous photographs are presented in figures 16 and 17 and 19 through 23 to illustrate, better than words ever could, the results of three successful Lunar Orbiter flights. The 610-mm photograph of the crater Copernicus, shown in figure 19, has been called the "Picture of the Century." An oblique shot of the prominent crater Kepler is shown in figure 16. This photograph was taken in hopes of confirming Russian reports of smoke arising from the crater floor, but, unfortunately, Kepler was quiet that day. The 610-mm photograph of the Earth from the Moon, shown in figure 20, is another first in space technology. A Lunar Orbiter III photograph of the Moon's farside is shown in figure 21.

Figure 22 is a typical 610-mm frame, taken from nominal photographic altitude and showing the vast amount of detailed information present in one photograph. This photograph, however, is especially interesting from another point of view. Located within the blocked off area in the center of the photograph is one of the outstanding achievements of the space age, the Surveyor I spacecraft. It might well be asked how so small an object was located within such a large frame (note that the figure as presented constitutes only part of a complete 610-mm frame). The best answer to this question is that it was known to be there, so it was found. An extensive effort was conducted, using isodensity traces, triangulation from Surveyor I photographs, and feature matching. Figure 23 is an enlargement showing the Surveyor spacecraft. One of the most conclusive pieces of evidence is shown in figure 24. This is one of the isodensity traces of the suspect object and shadow. Superimposed on the trace is a photograph of a Surveyor model, at the same scale and sun angle. The evidence is considered conclusive that the Surveyor I was found, and its photograph is particularly interesting in that, for the first time, an object of known dimensions was photographed on the lunar surface for comparison with theory. Spacecraft details are not visible in the photograph for two reasons: (1) the Surveyor spacecraft is very close to the Lunar Orbiter resolution limit at this altitude, and (2) the highlight caused by reflection from the spacecraft exceeds the dynamic range of the Lunar Orbiter system.

It is appropriate to consider some of the reasons for the success of the Lunar Orbiter program. It is felt that one of the outstanding reasons, apart from excellent design, development, and manufacturing efforts by the many industrial participants, is the very fact that Lunar Orbiter is a true photographic system, using photographic film as the data storage medium. It would be unrealistic to say that there were never any doubts. These doubts were at the maximum when a seemingly endless series of problems plagued the system's mechanisms, particularly the extremely complex film-handling system, with its 71 rollers, 5 motors, and multitude of bearings, film separators, clamps, and so forth. However, no state-of-the-art storage medium exceeds film in storage capacity per pound of system weight, and no practical system exists for gathering data as fast as a wide-angle camera of high repetition rate. Once over the problems of mechanical complexity and with enough payload weight allowance to provide adequate shielding against solar radiation, film-type systems appear to have a future in the longer and more demanding deep space missions of the future.

As for the immediate future, the Lunar Orbiter Project looks forward to successful completion of the remaining flights in the program. If all goes well, by the end of May 1967 very little of the Moon's surface, both nearside and farside, will remain unknown and unmeasured. The lunar jigsaw puzzle is gradually being pieced together, and the Moon is becoming a more hospitable target for the astronaut of today and the scientist of both today and tomorrow.

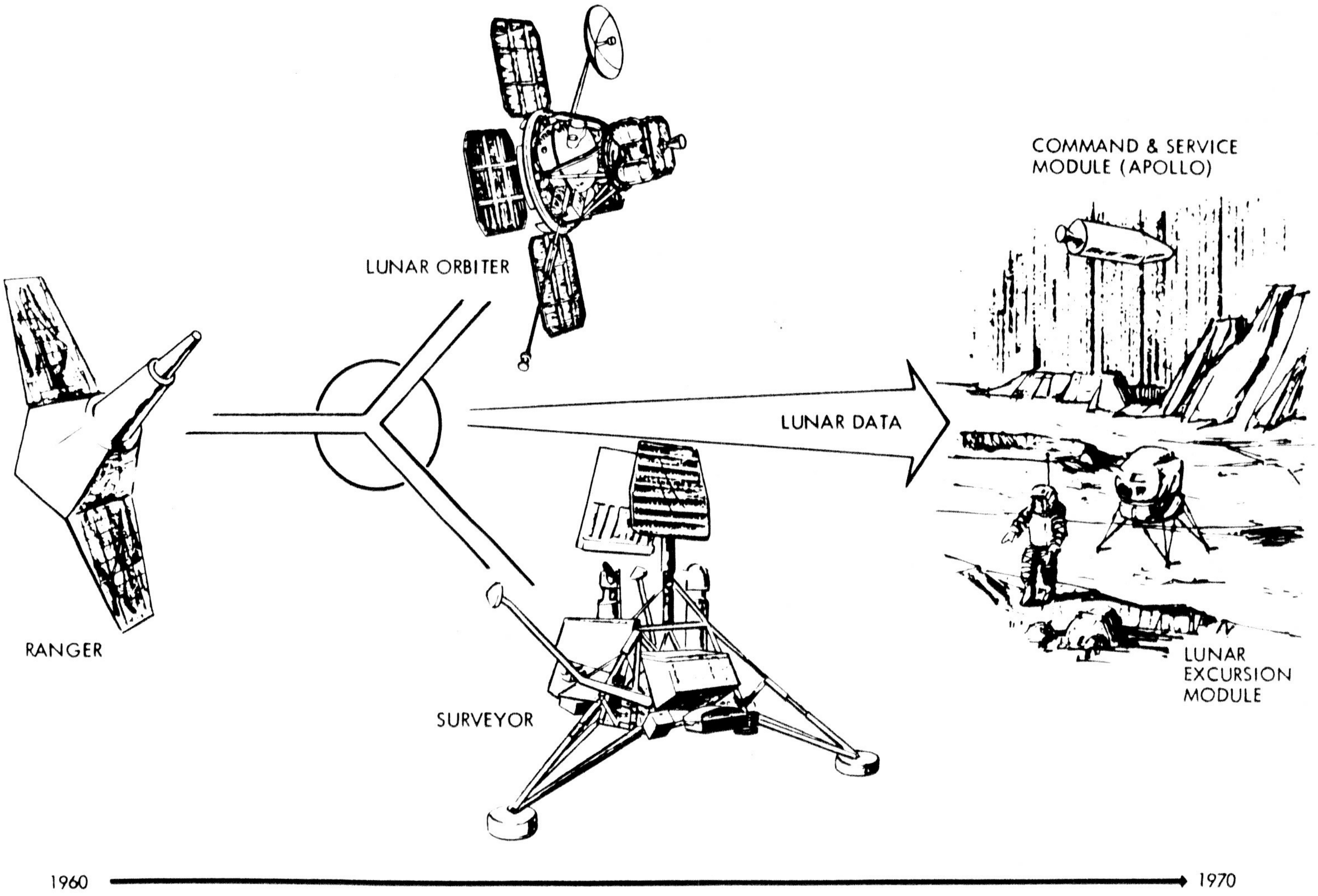

Figure 1.- Unmanned program support for Apollo.

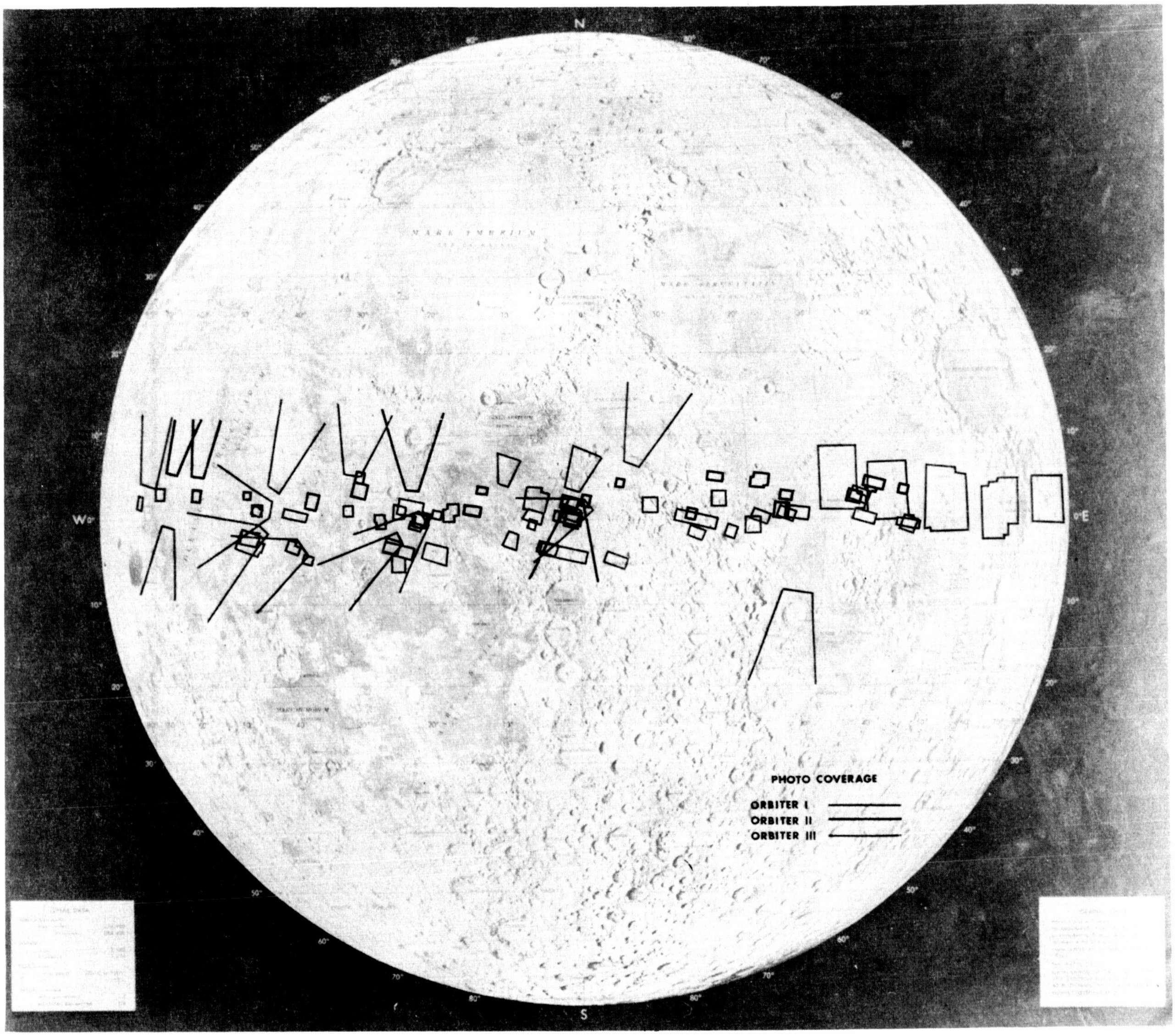

Figure 2.- Lunar Orbiter I, II, and III - photographic coverage.

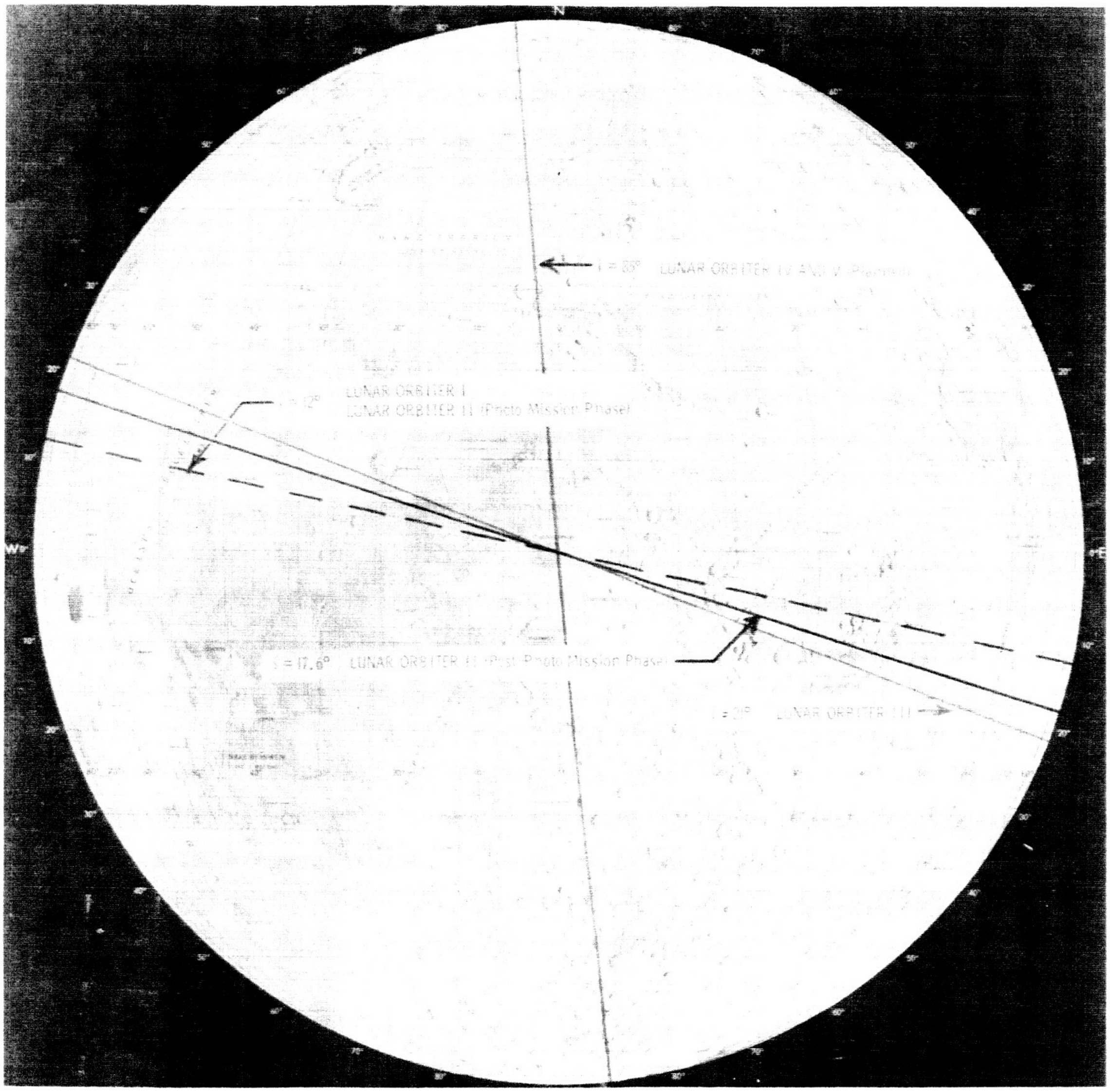

Figure 3.- Orbits for Lunar Orbiter Missions.

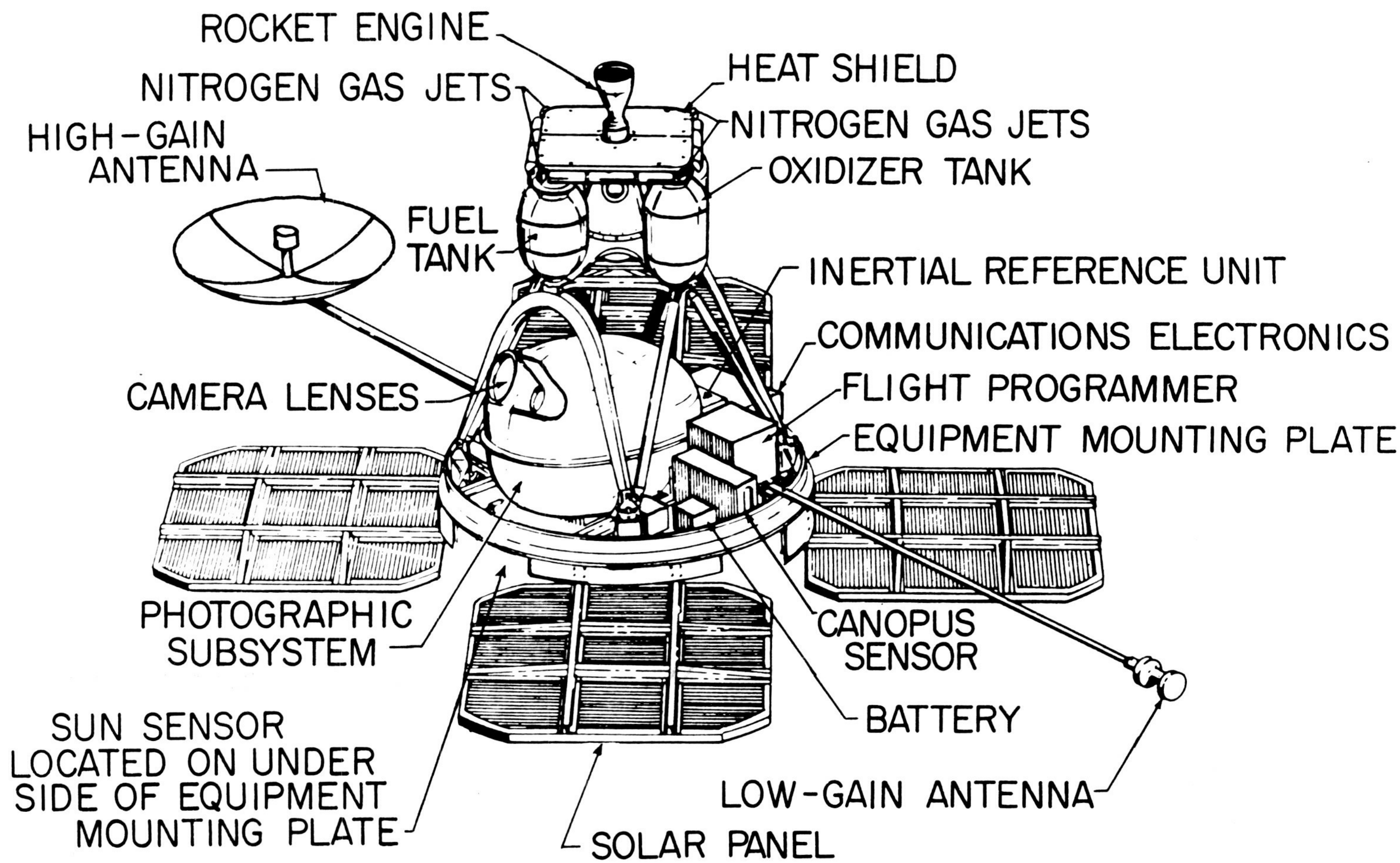

Figure 4.- Spacecraft configuration.

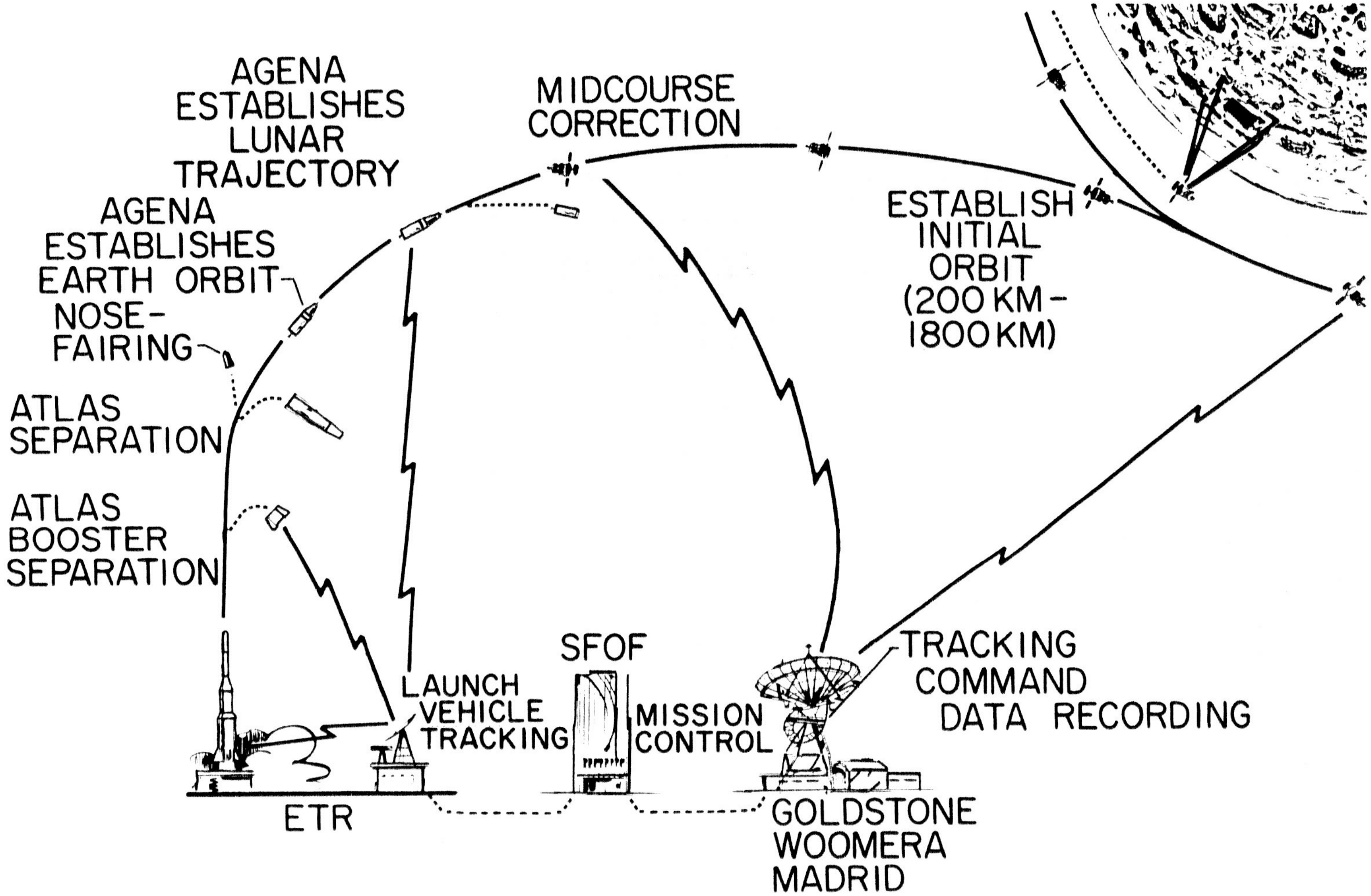

Figure 5.- Mission operations.

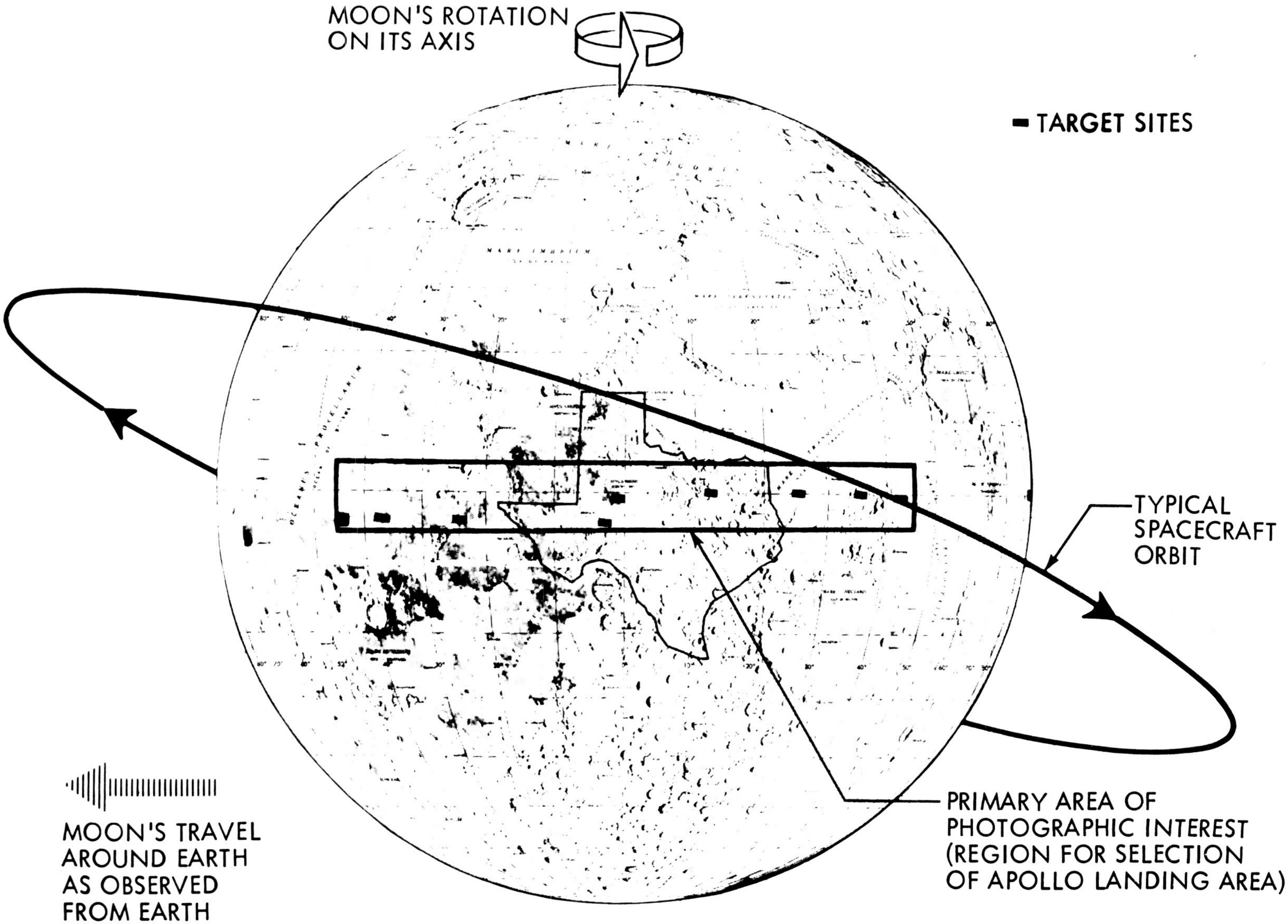

Figure 6.- Lunar surface photographic coverage.

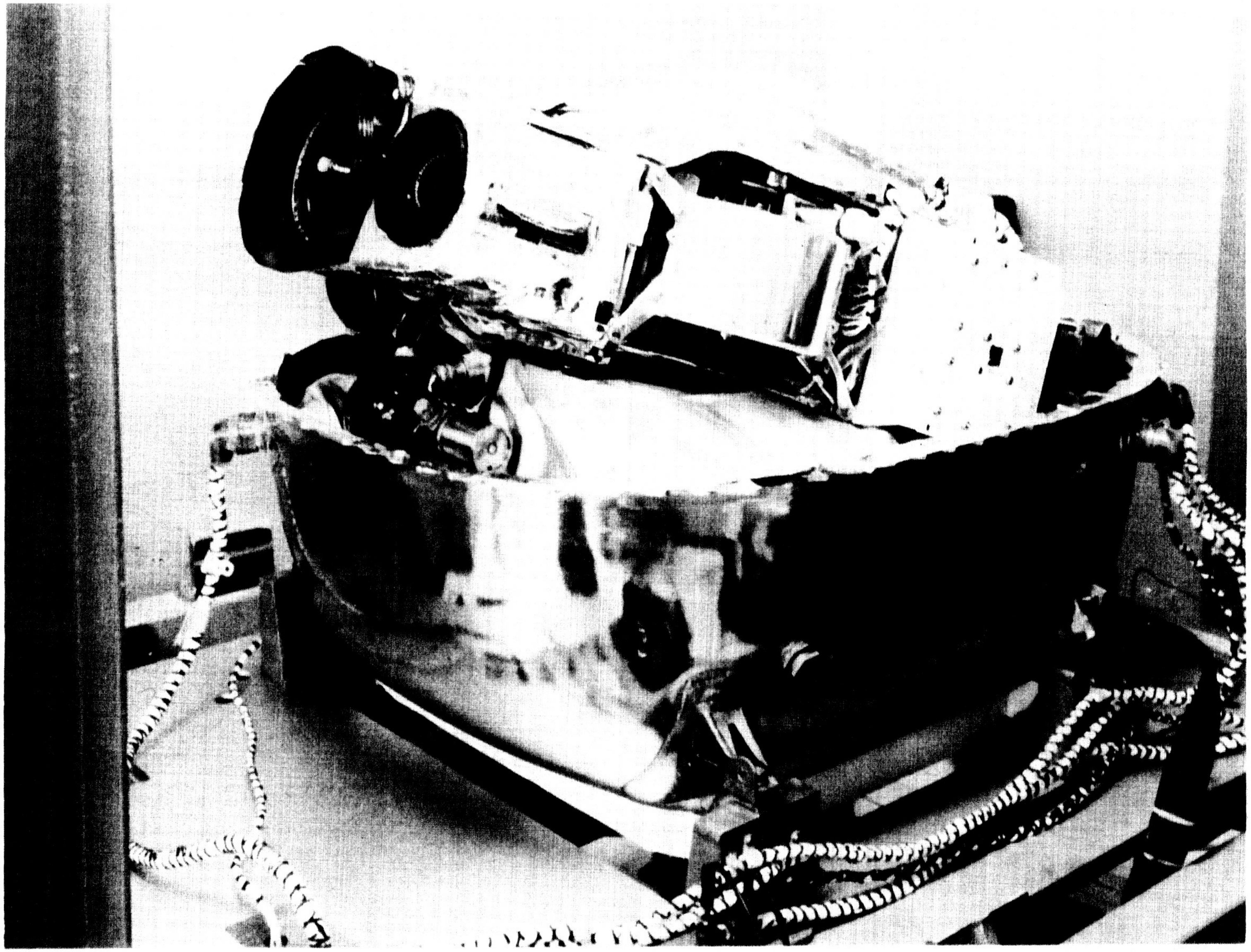

Figure 7.- Photographic system.

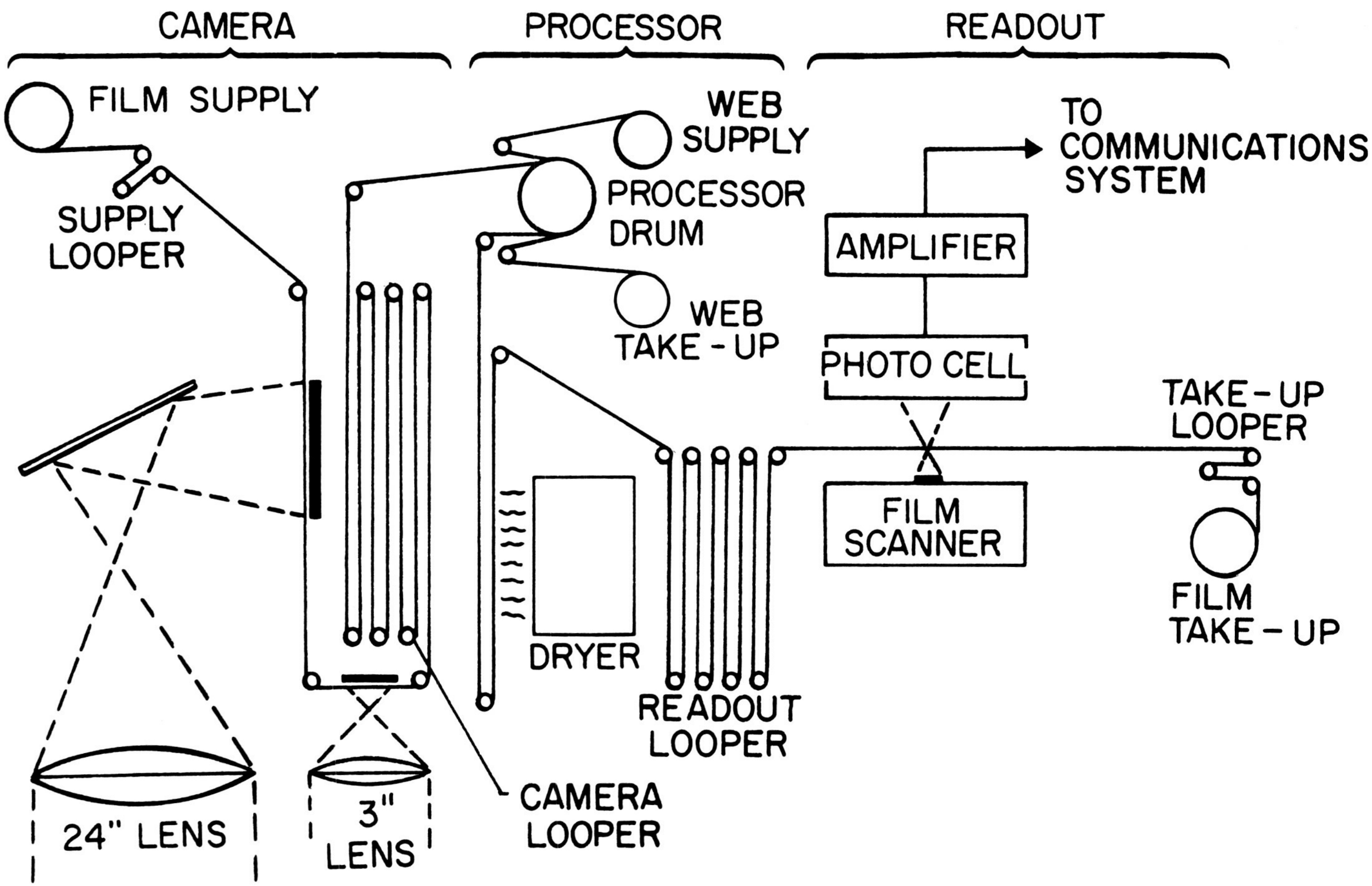

Figure 8.- Photographic system schematic.

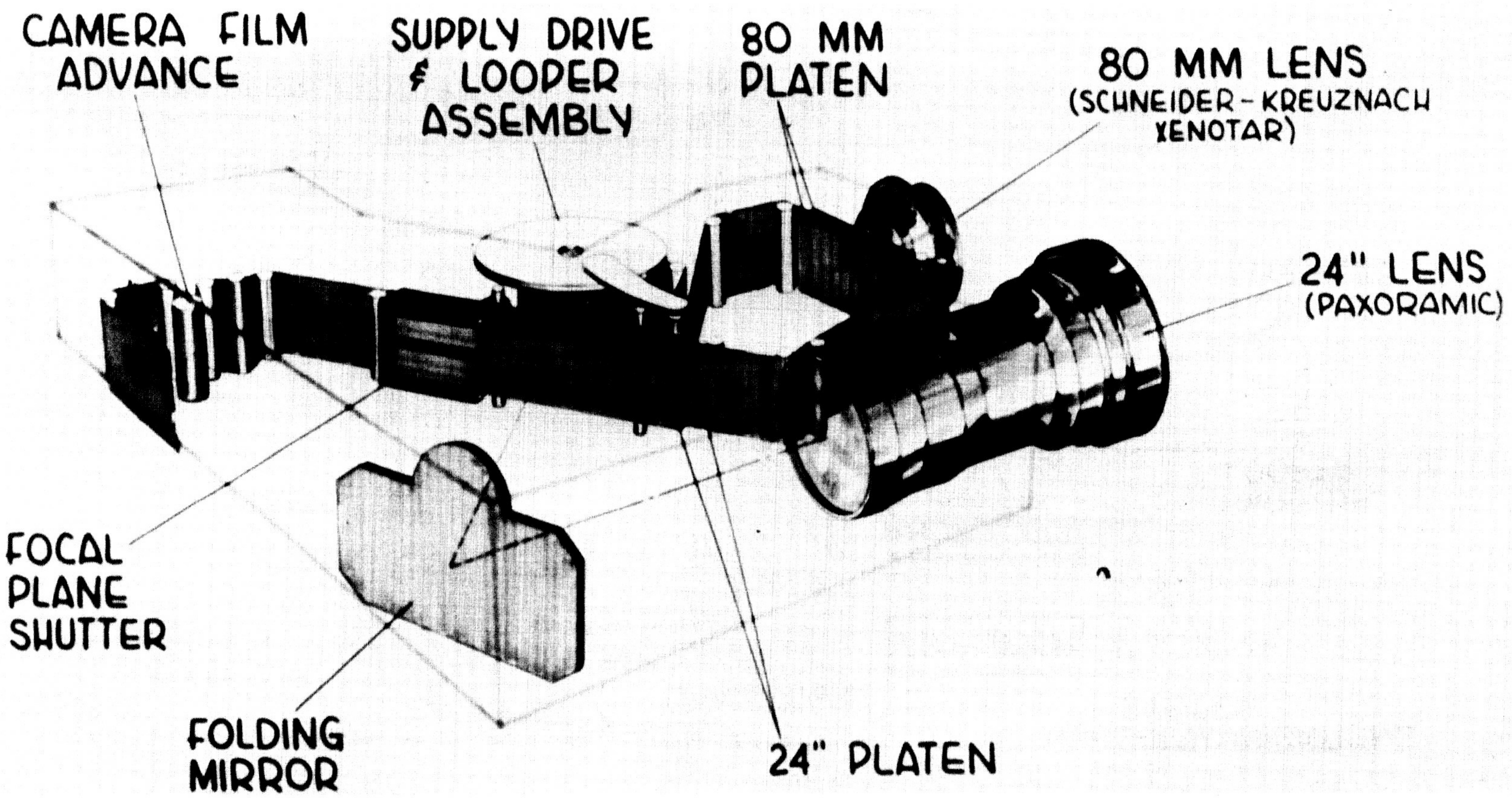

Figure 9.- Camera.

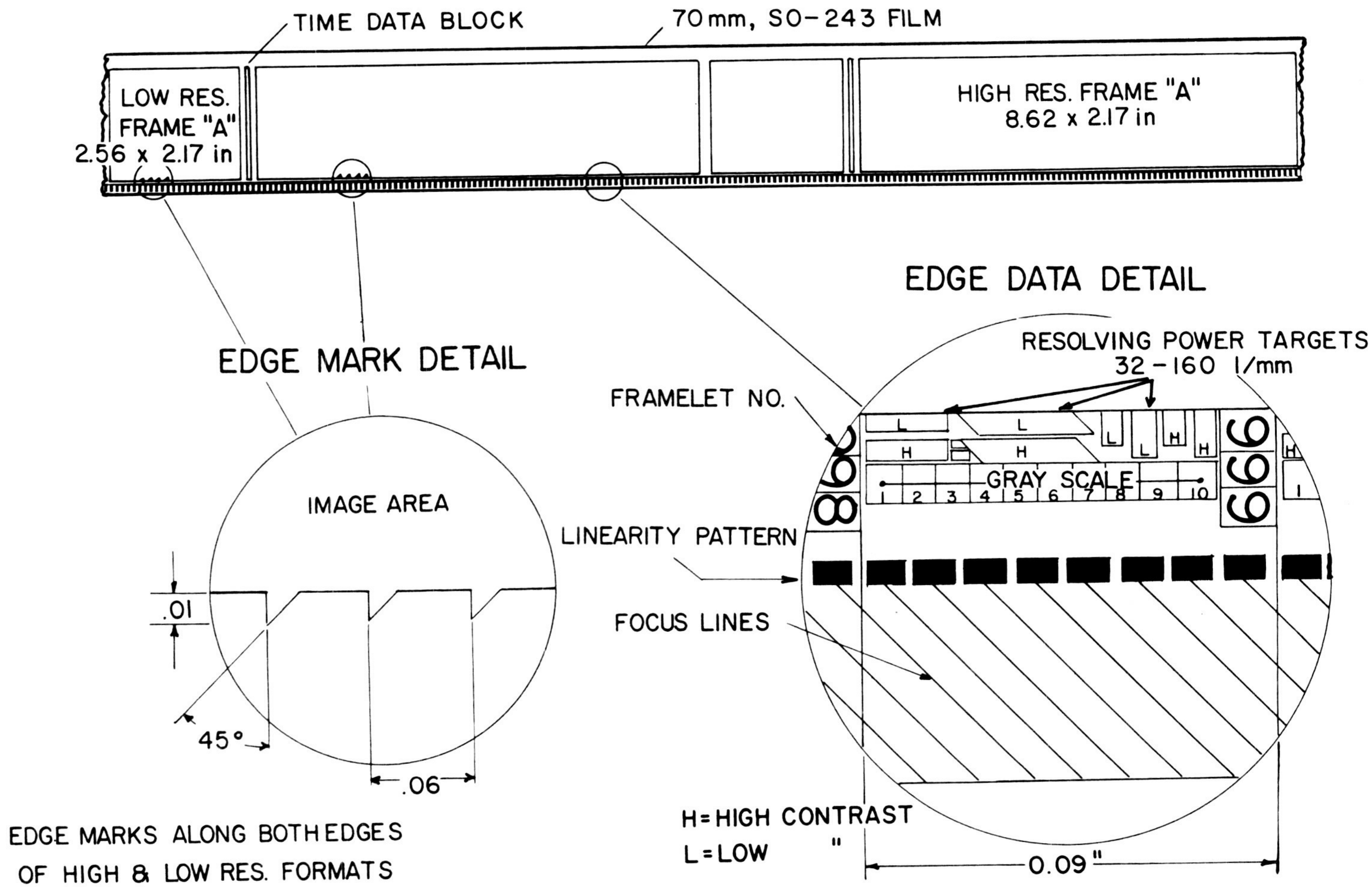

Figure 10.- Spacecraft film format.

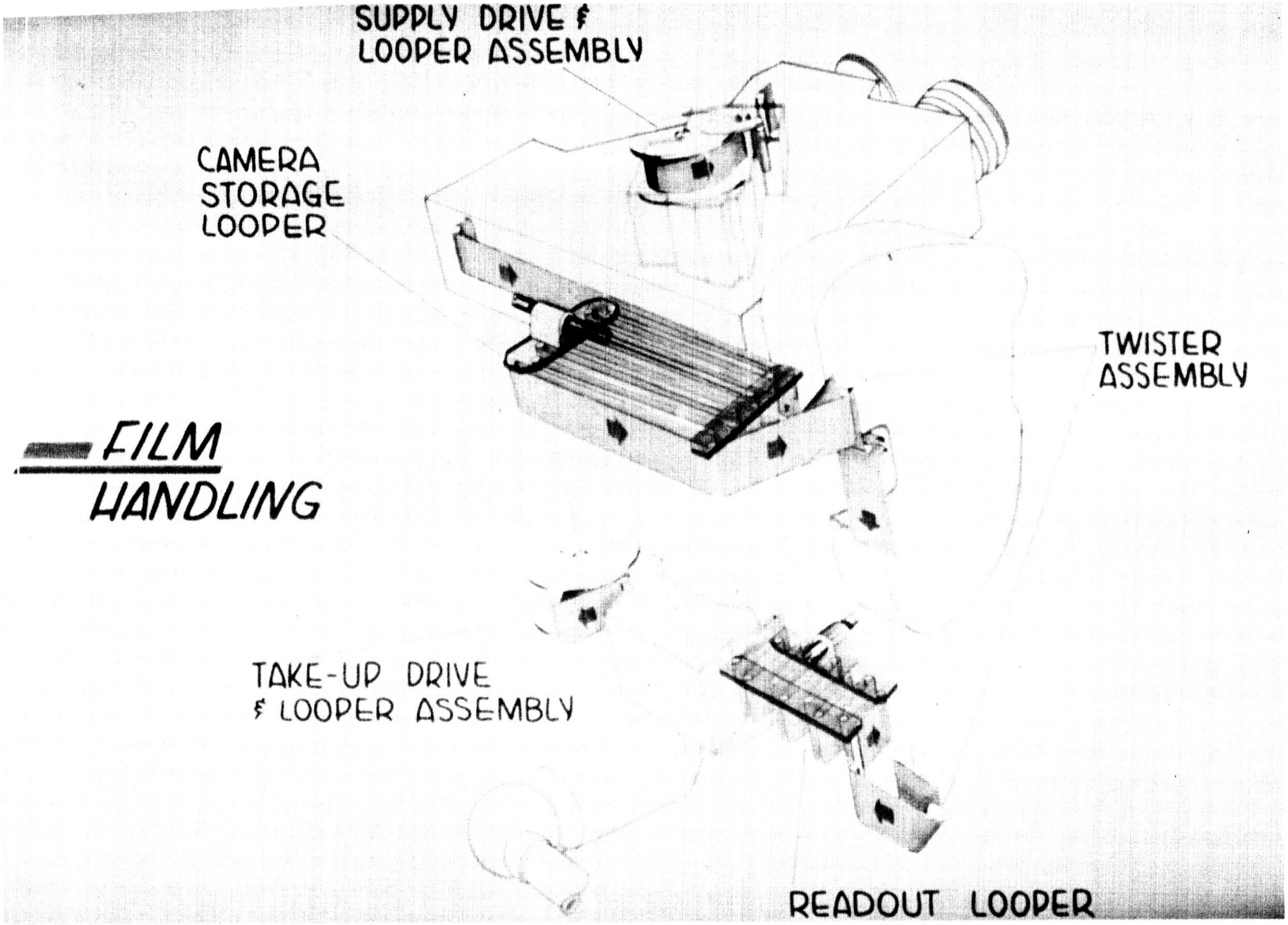

Figure 11.- Film handling.

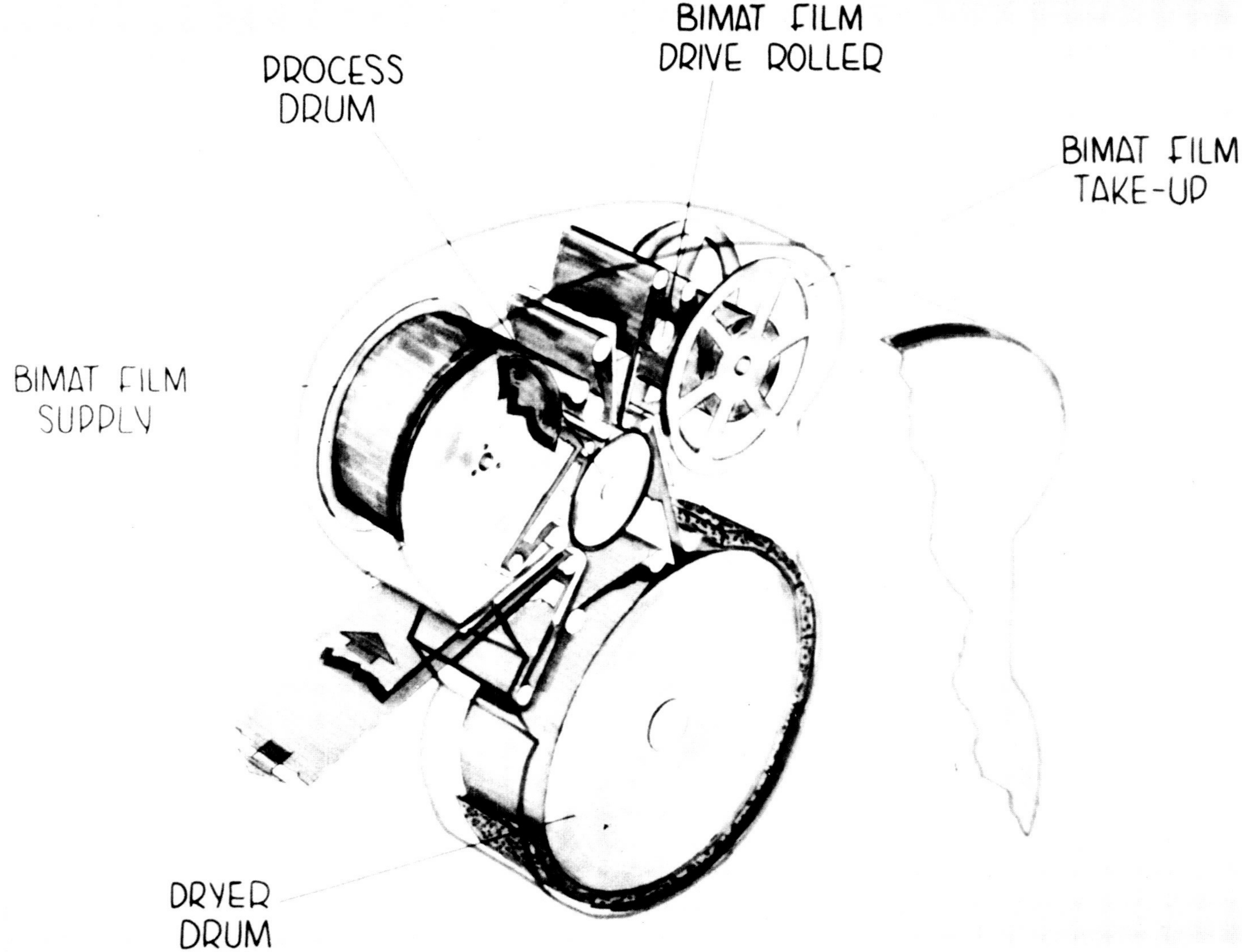

Figure 12.- Processor/Dryer.

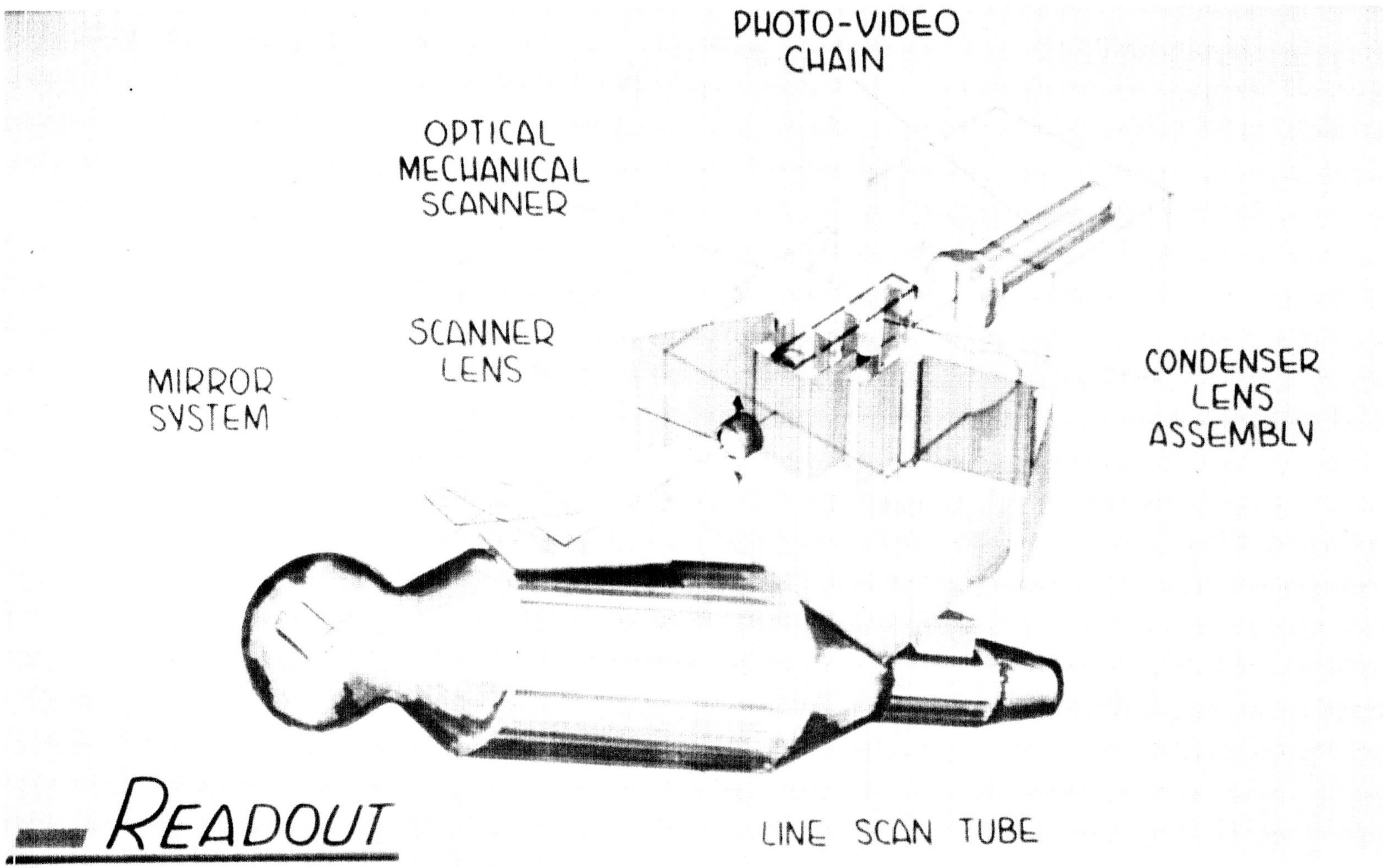

Figure 13.- Readout.

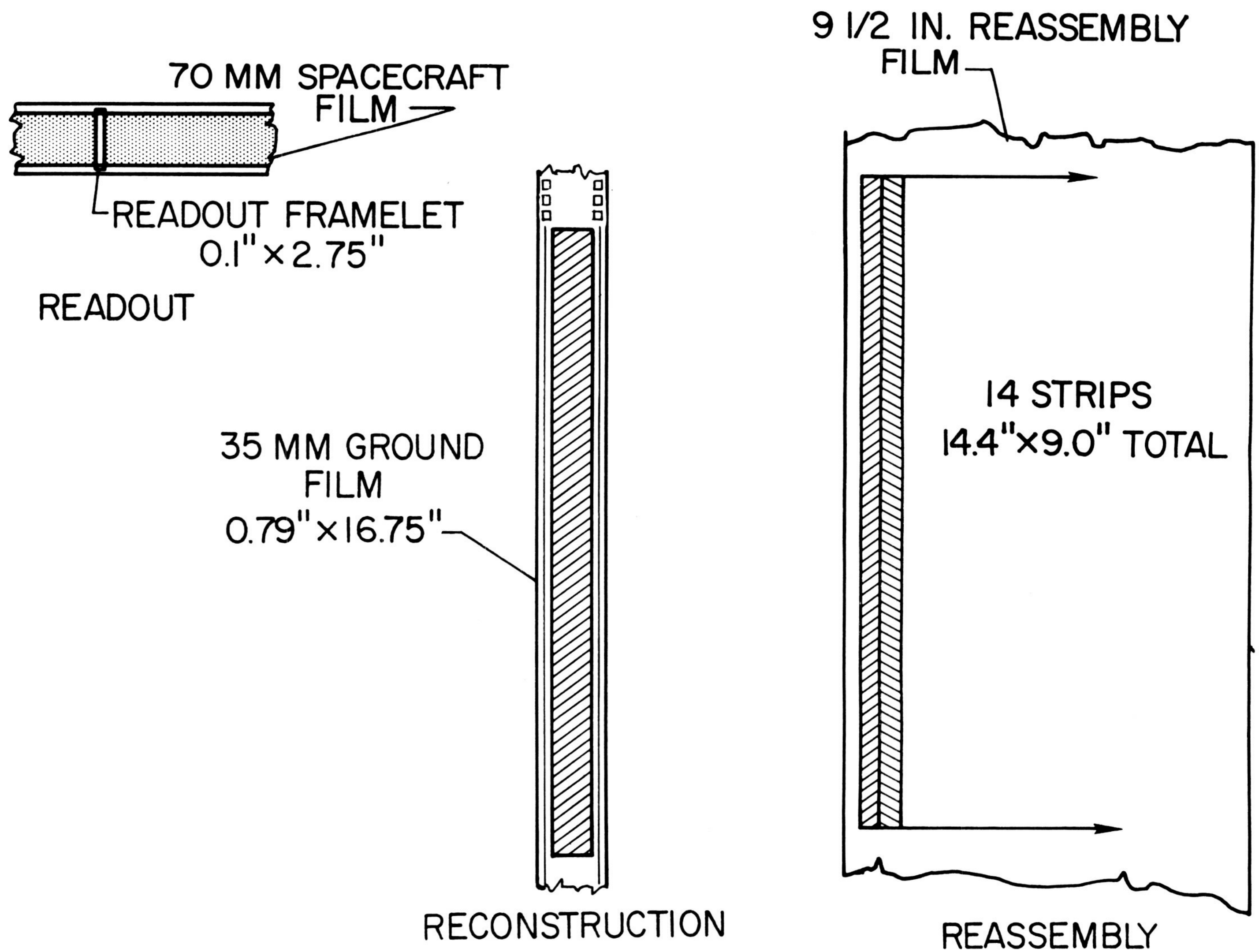

Figure 14.- Reassembly geometry.

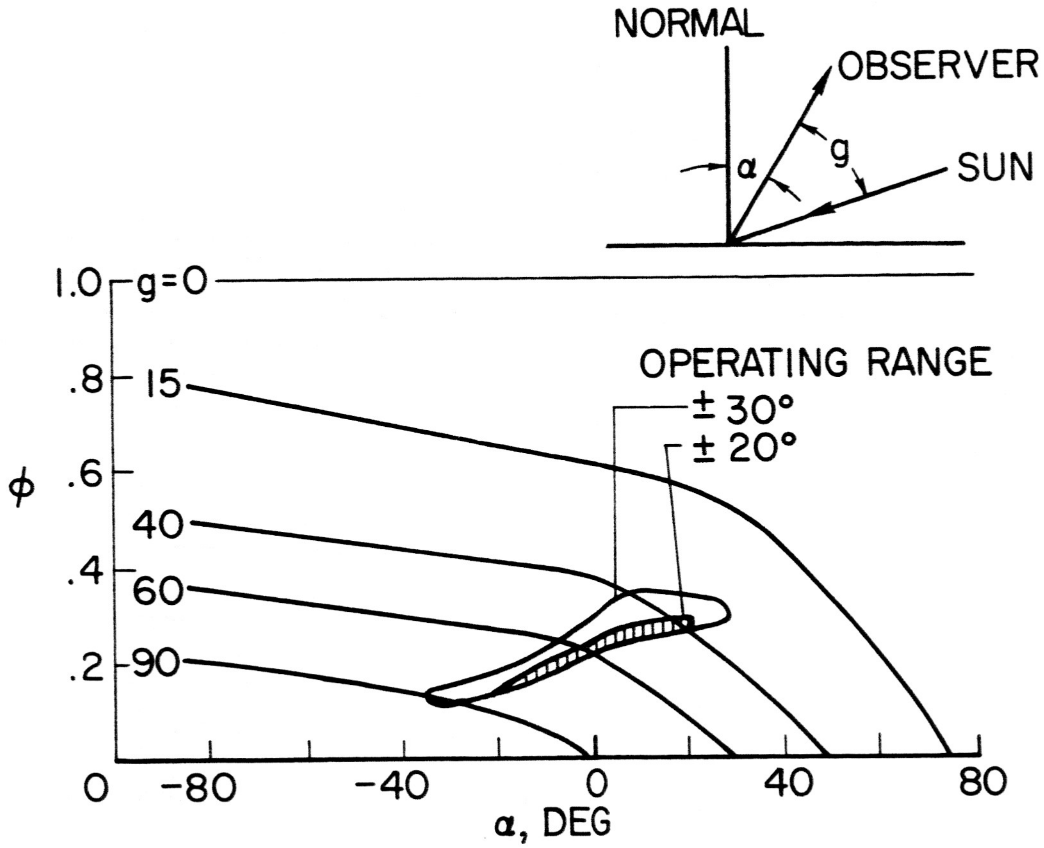

Figure 15.- Lunar photometric function.

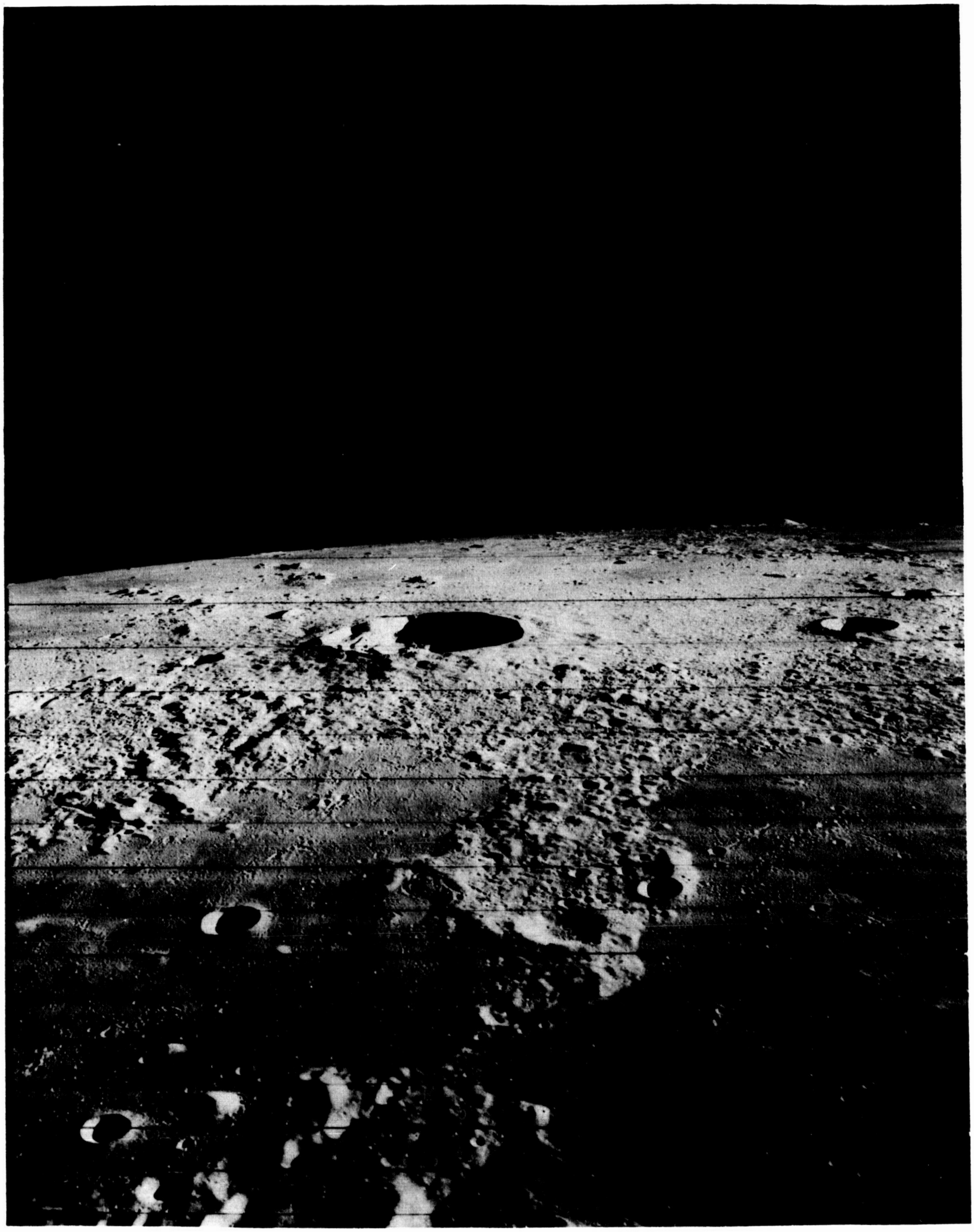

Figure 16.- Lunar orbiter III photographic, Kepler.

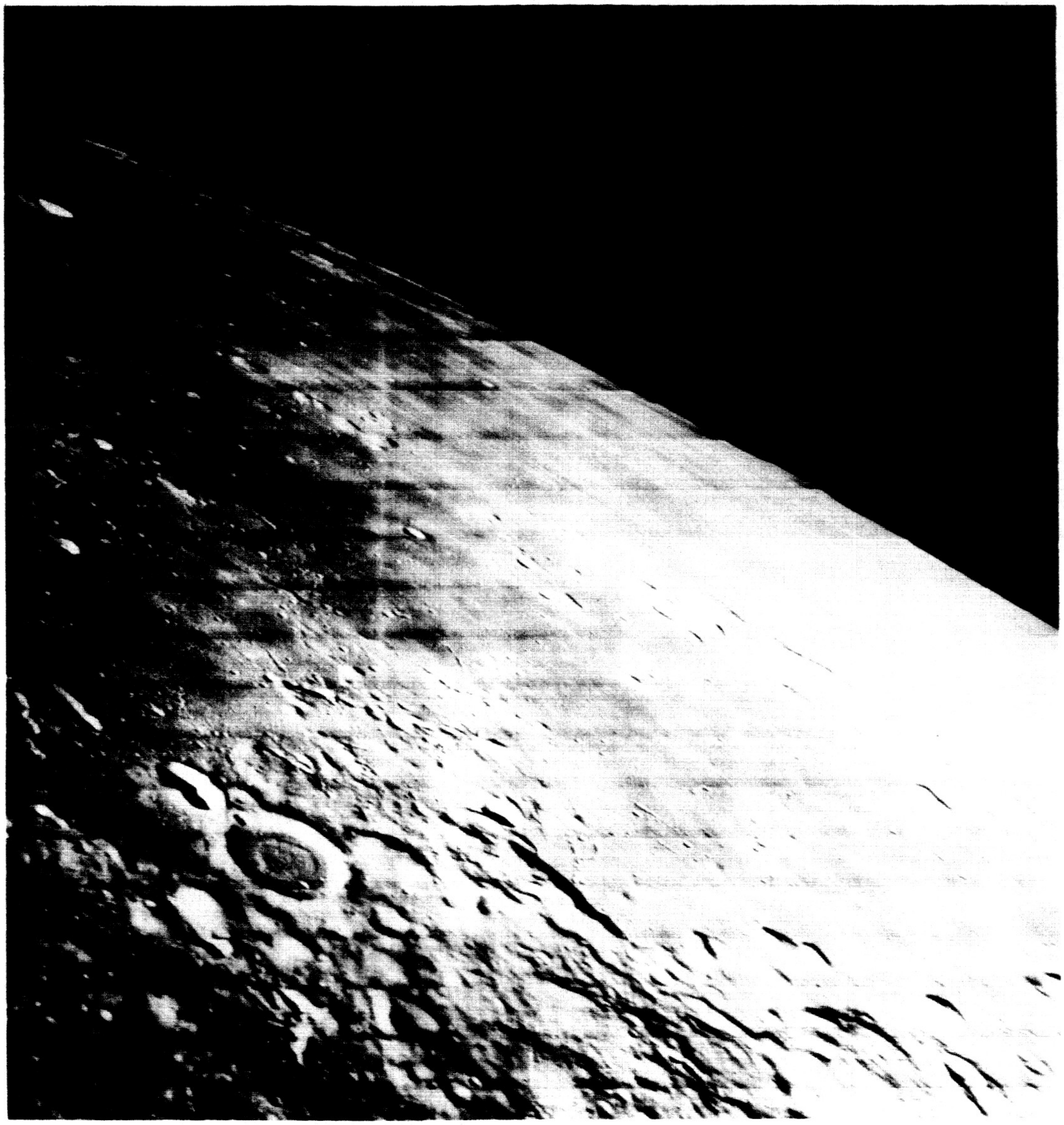

Figure 17.- Lunar orbiter III photographic, Westward Oblique.

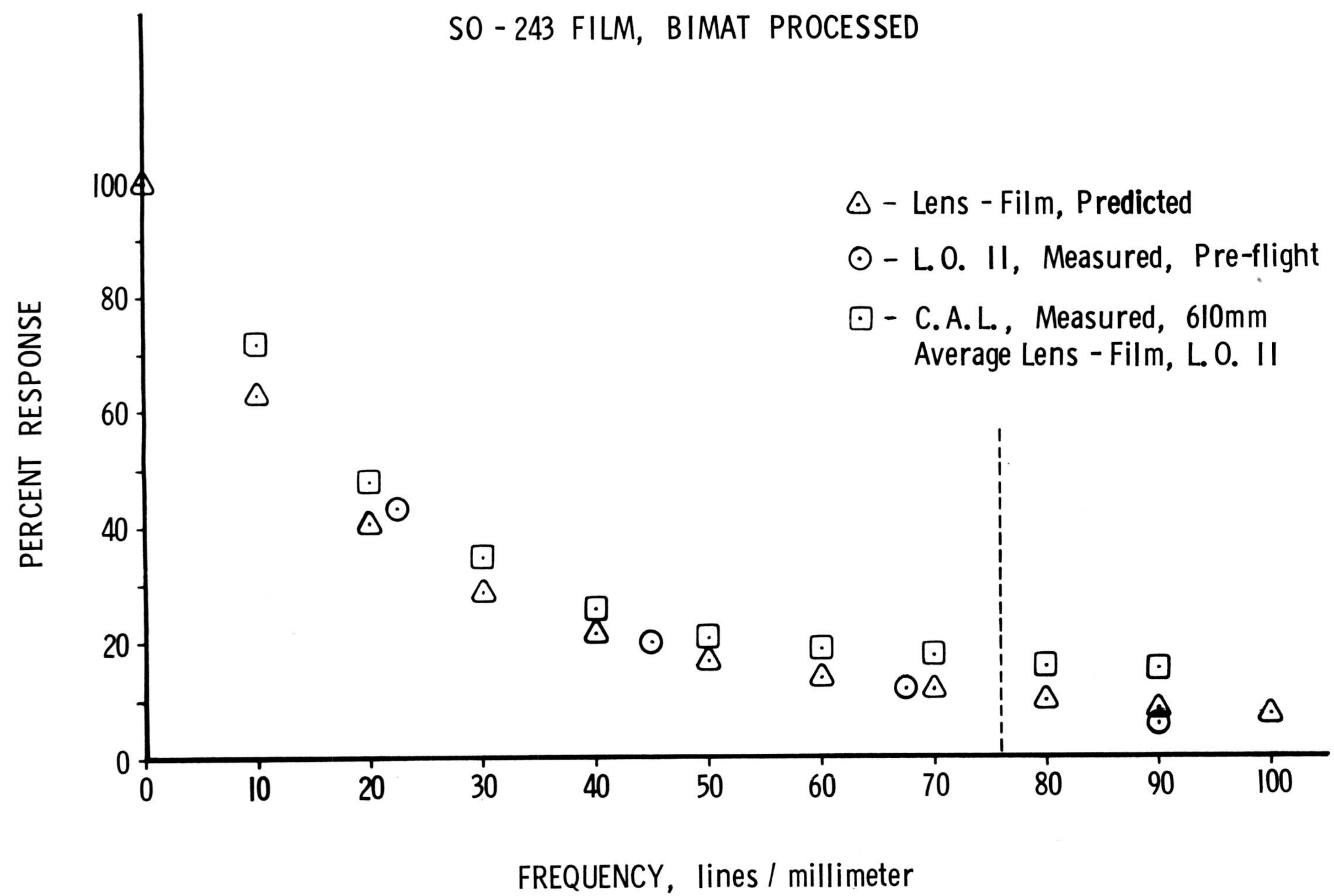

Figure 18.- 610 mm MTF, "on axis."

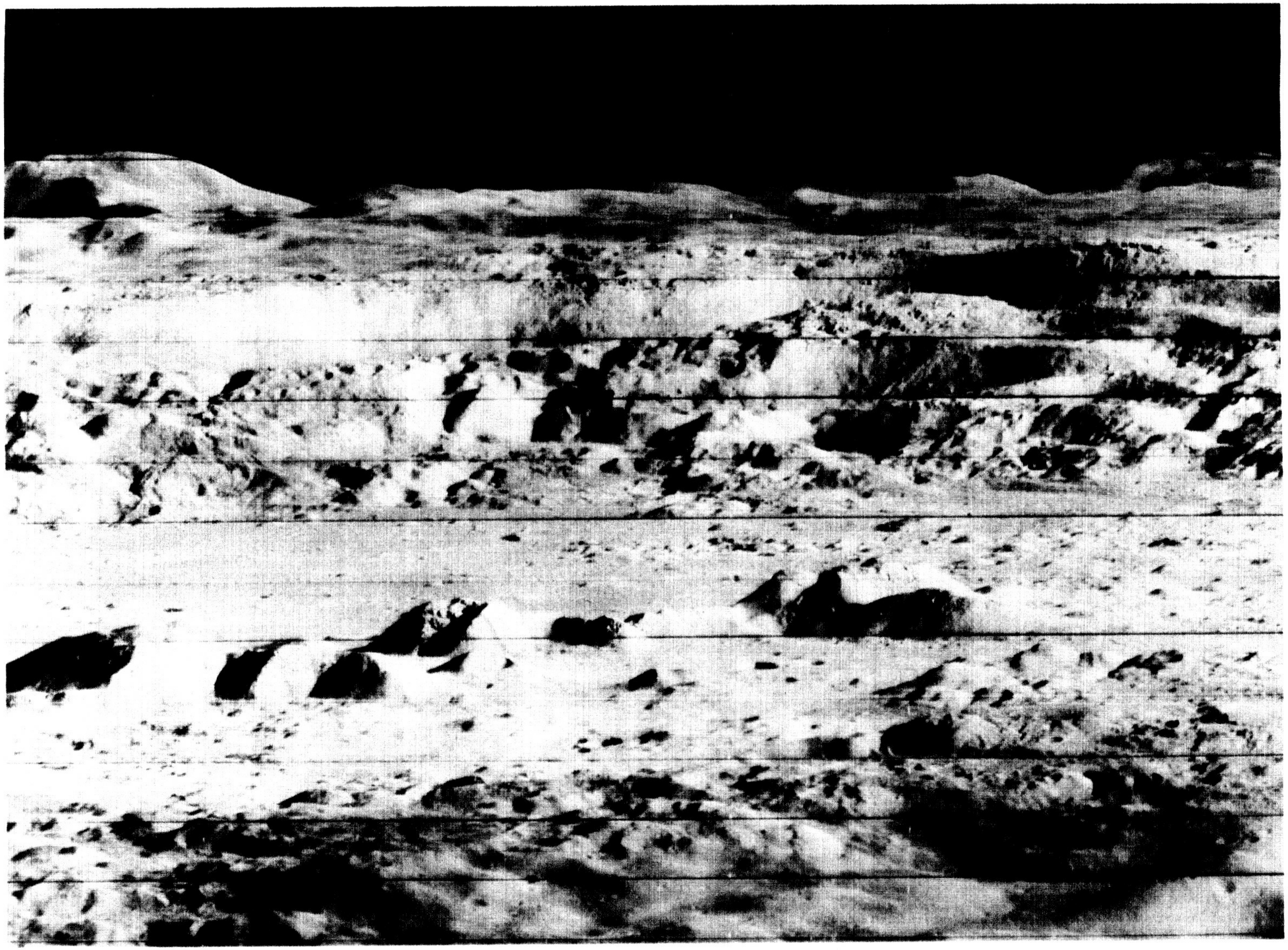

Figure 19.- Lunar orbiter II photograph, Copernicus.

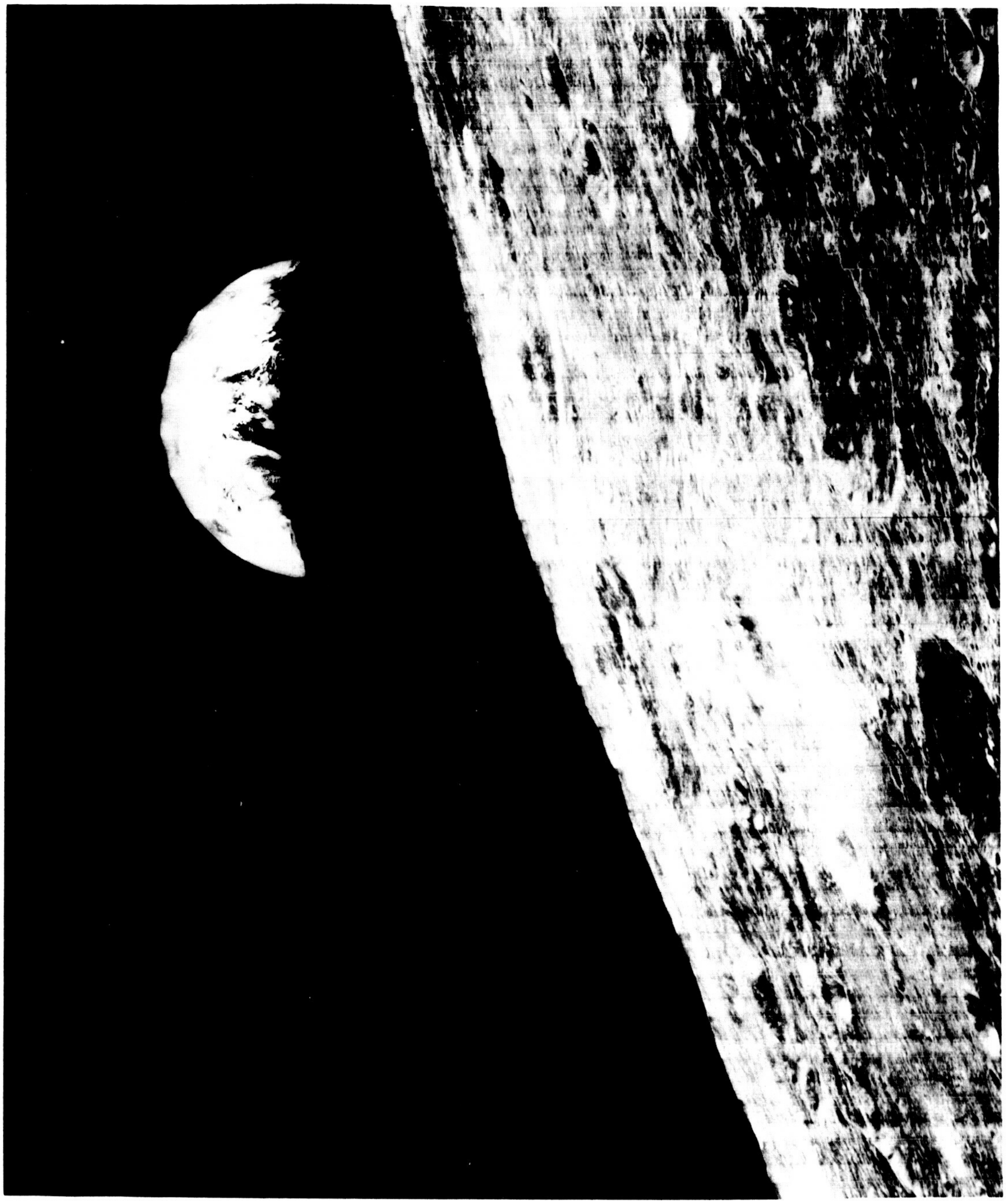

Figure 20.- Lunar orbiter I photograph, Earth-Moon.

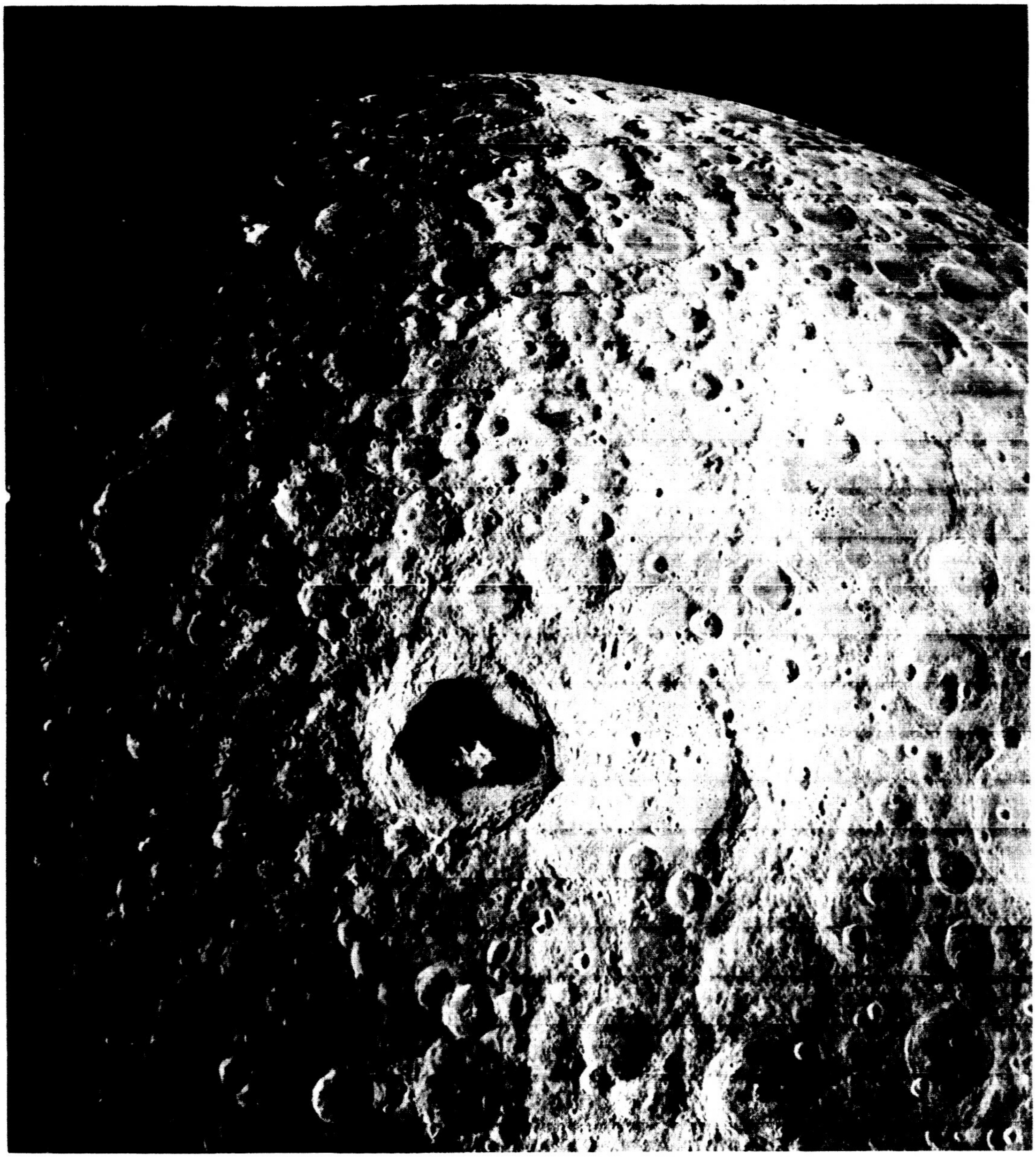

Figure 21.- Lunar orbiter III photograph, Farside.

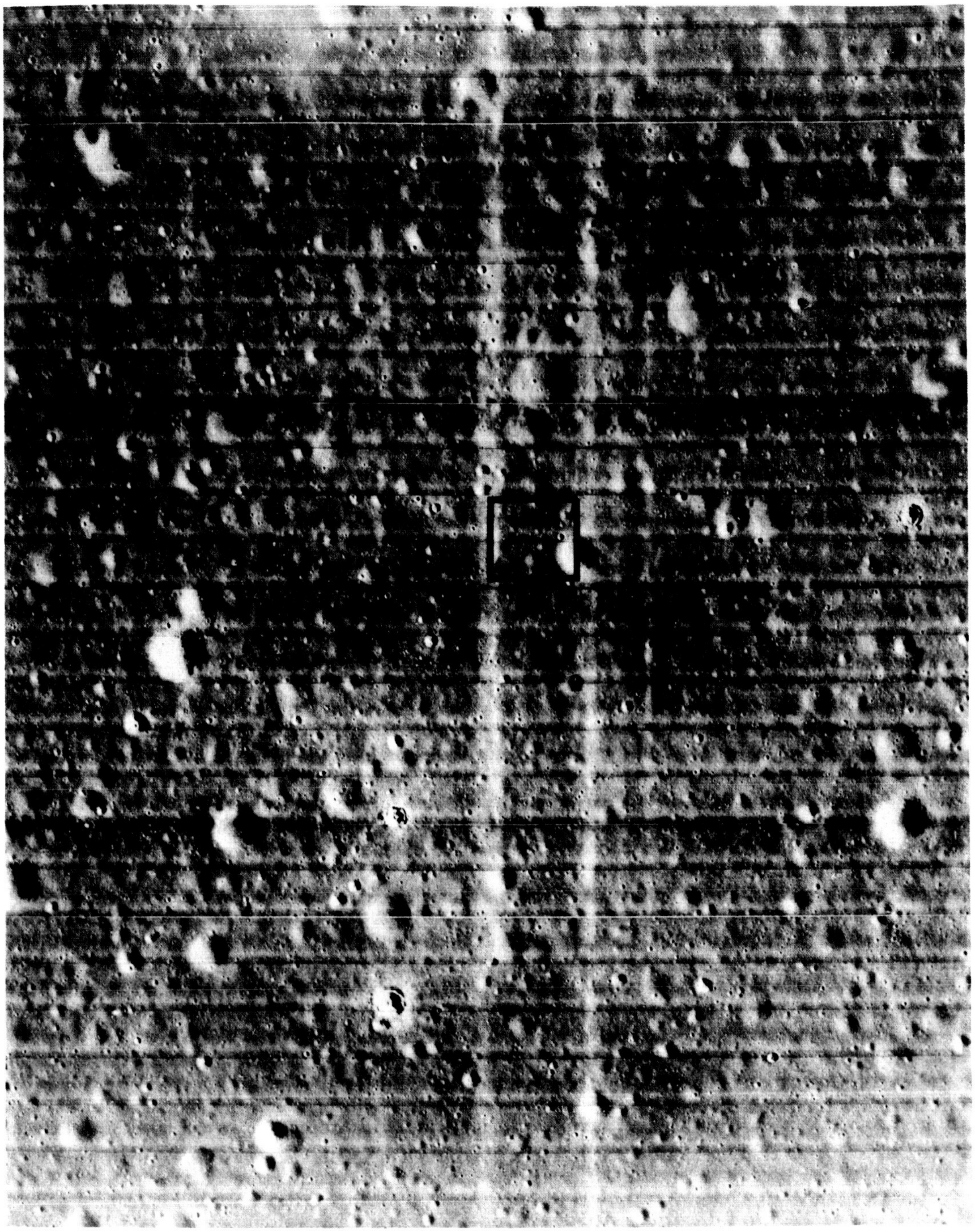

Figure 22.- Lunar orbiter III photograph, Oceanus Porcellarum.

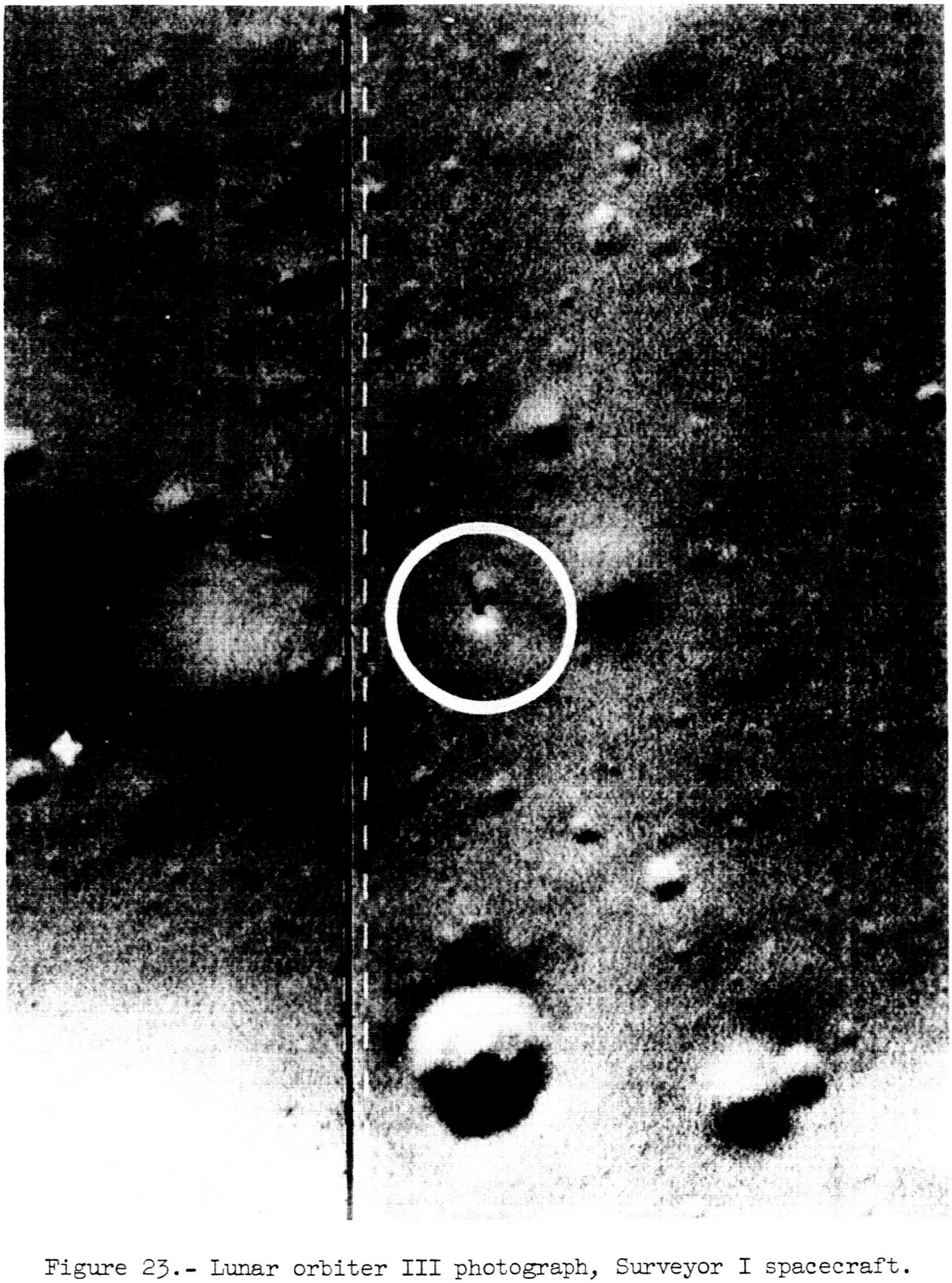

Figure 23.- Lunar orbiter III photograph, Surveyor I spacecraft.

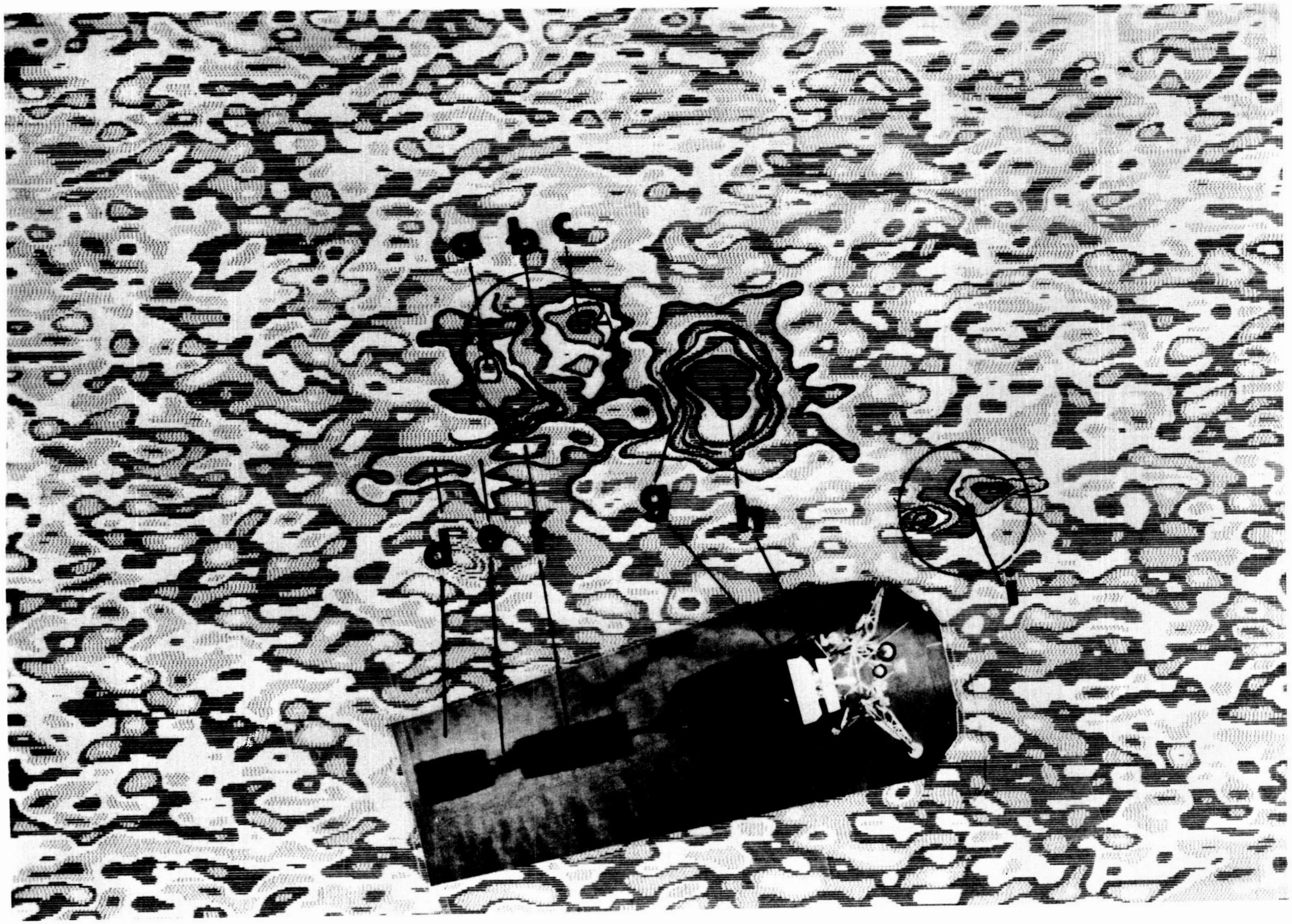

Figure 24.- Isodensity contours of Surveyor I shadow.

NASA-Langley, 1967